Analysis of Filter Transmission Uniformity Specifications

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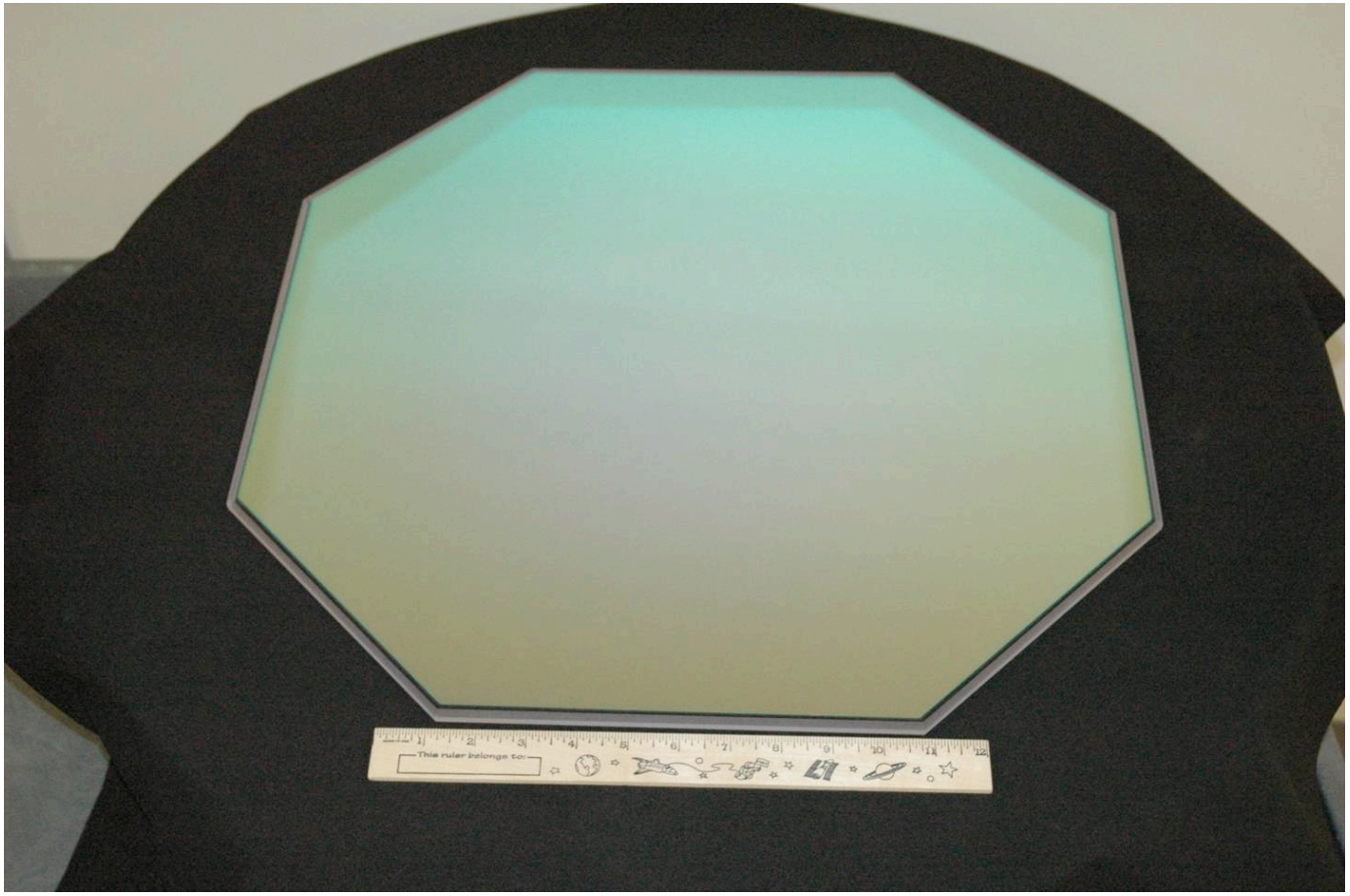
PanSTARRS Filters from Barr



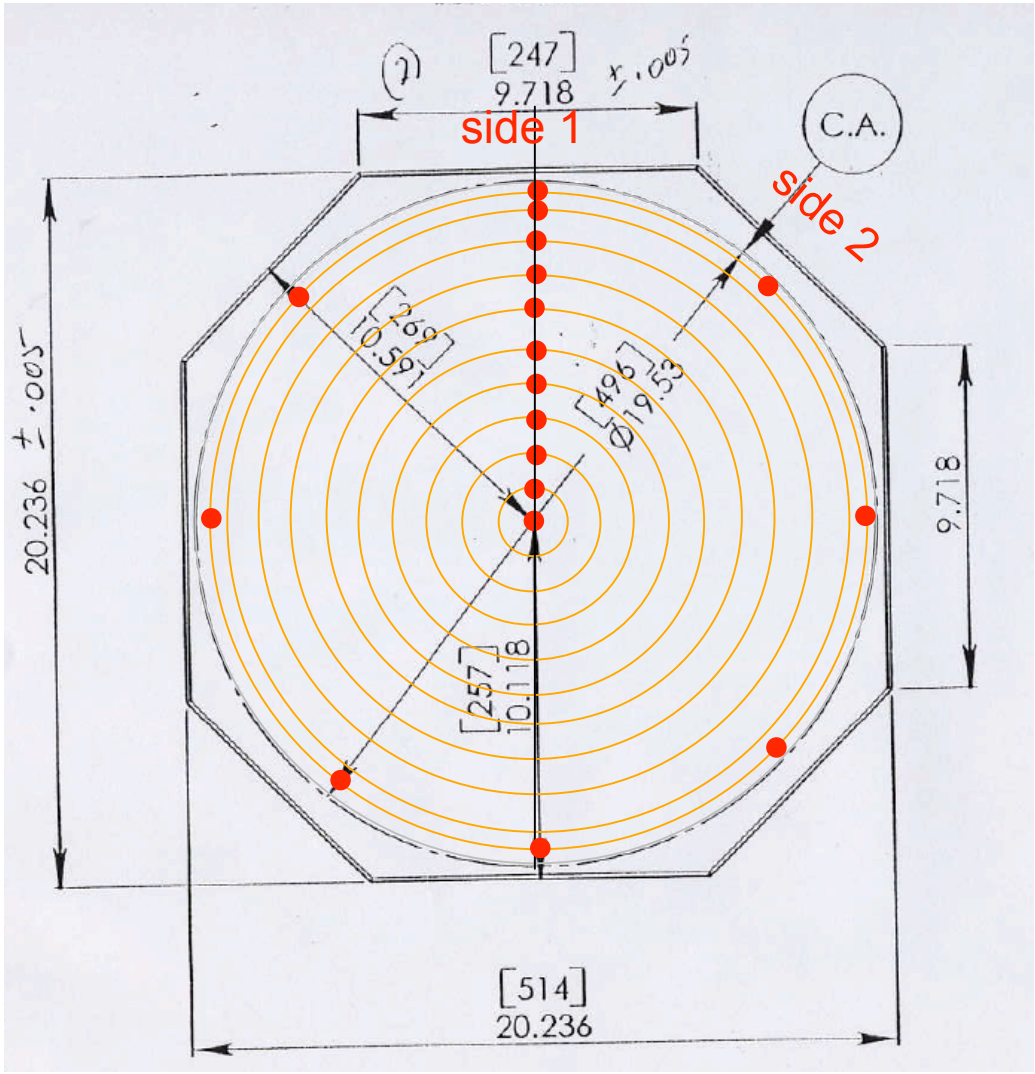
- ***Similar to DES filters:***
  - ***570 mm size***
  - ***10 mm thick***
  - ***Fused silica substrates***
- ***Data on griz filters available***

PanSTARRS i-band filter

from B. Bigelow

PanSTARRS Filter

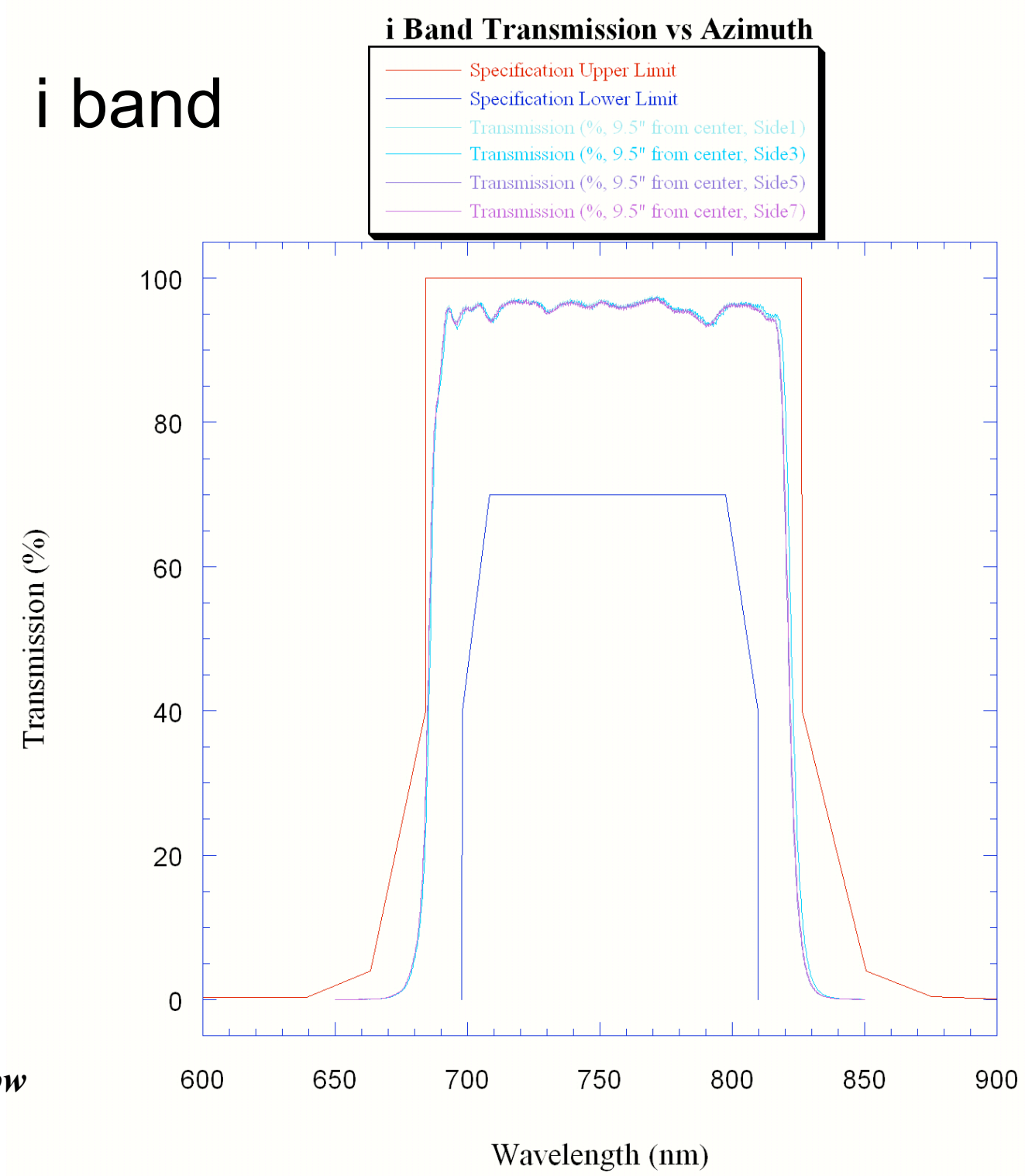
- The red dots are the positions where the filters were evaluated.
- 9 *radial* points every 1”, last point at 9.5”
- I’m calling these positions 1-11, from center to edge
- Position 7 is used as reference
- Eight *azimuthal* points



adapted from M. Schubnell

DARK ENERGY SURVEY

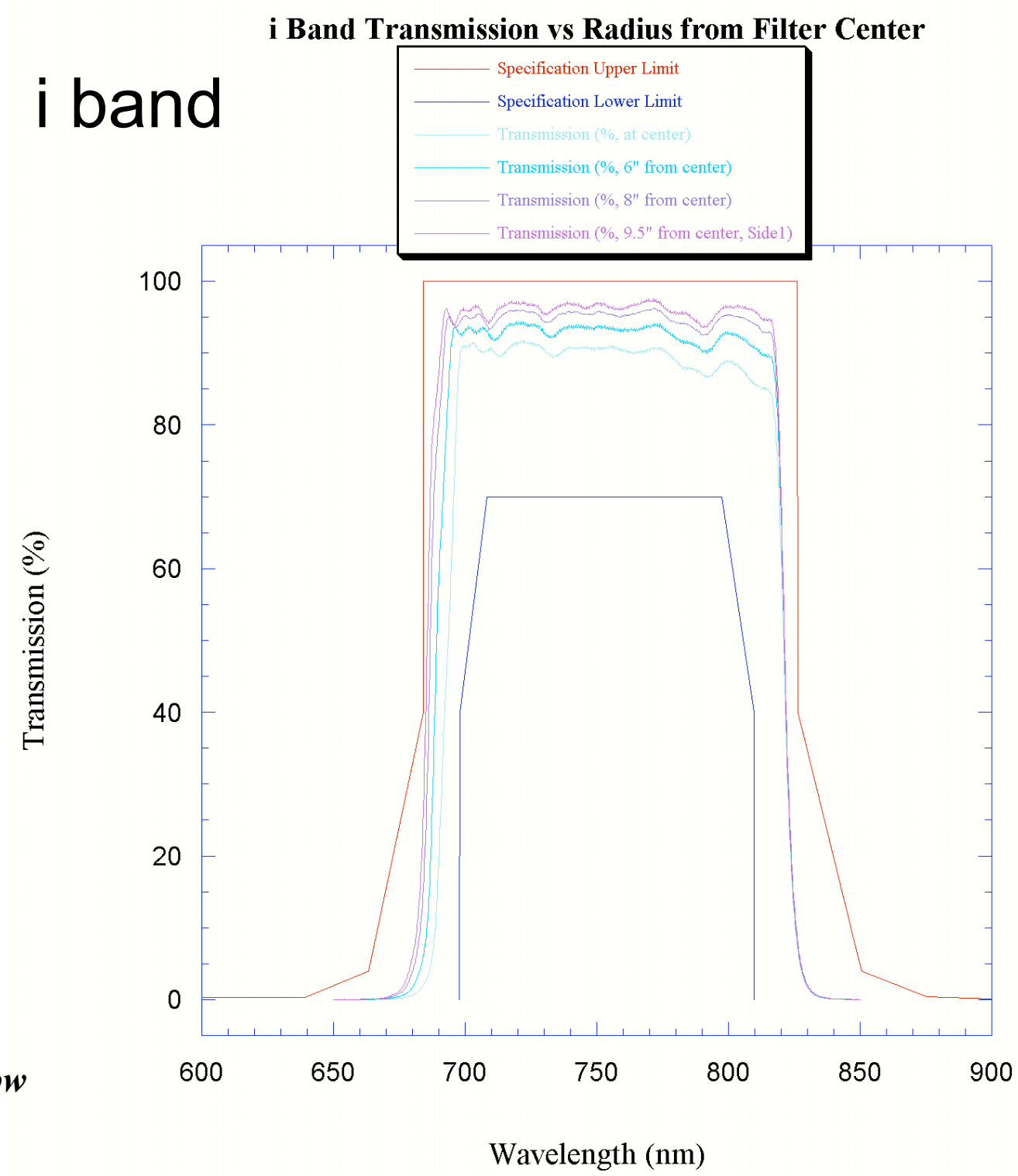
i band



from B. Bigelow

DARK ENERGY SURVEY

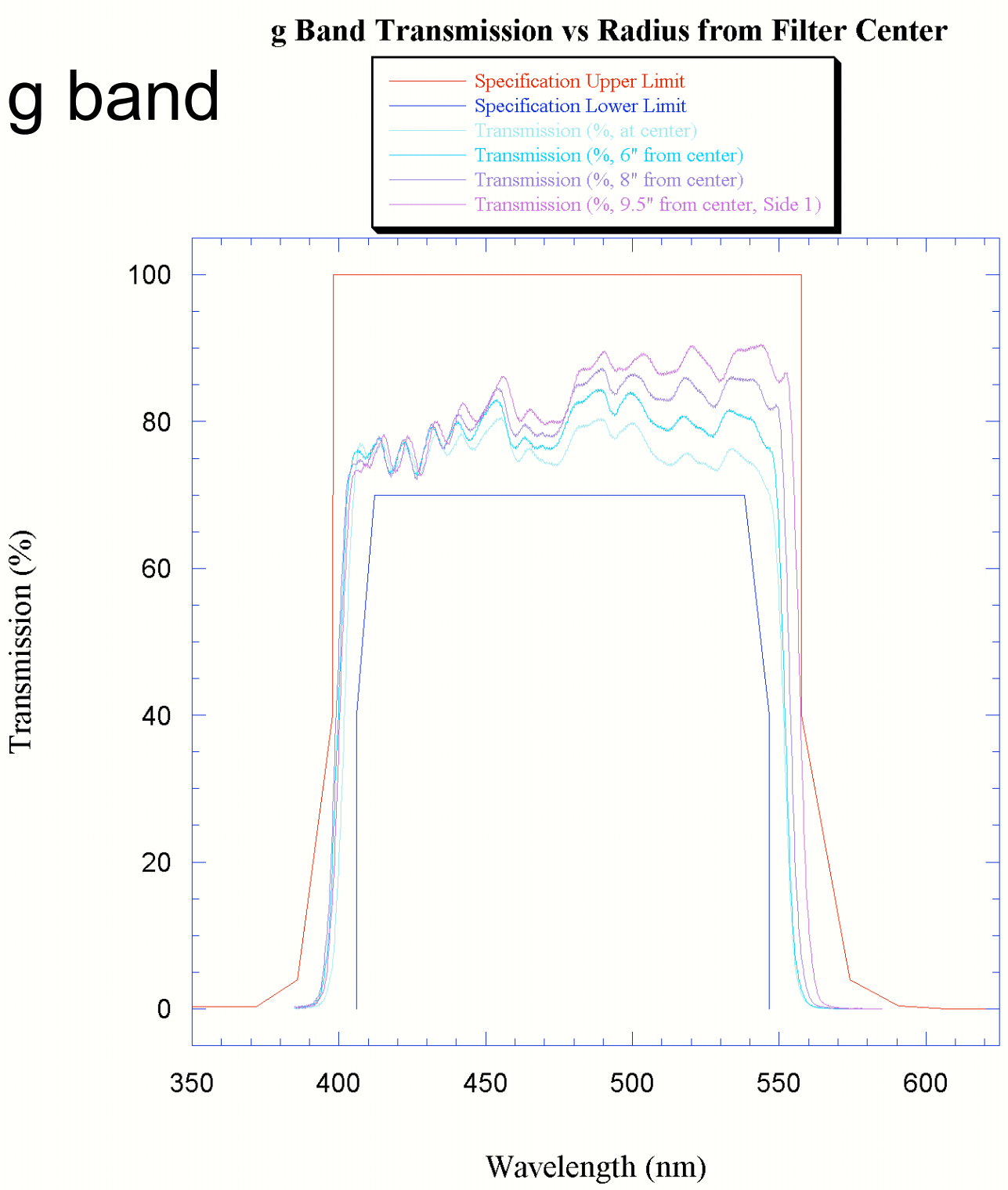
i band



from B. Bigelow

DARK ENERGY SURVEY

g band



from B. Bigelow

Filter Transmission Uniformity Analysis

- **Give filter specifications to vendors using upper and lower absolute transmission envelopes, similar to PanSTARRS filters**

- **DES photometric calibration requirement is 2%; assign 1% error budget component to filters to account for spatial non-uniformity in filter transmissions**

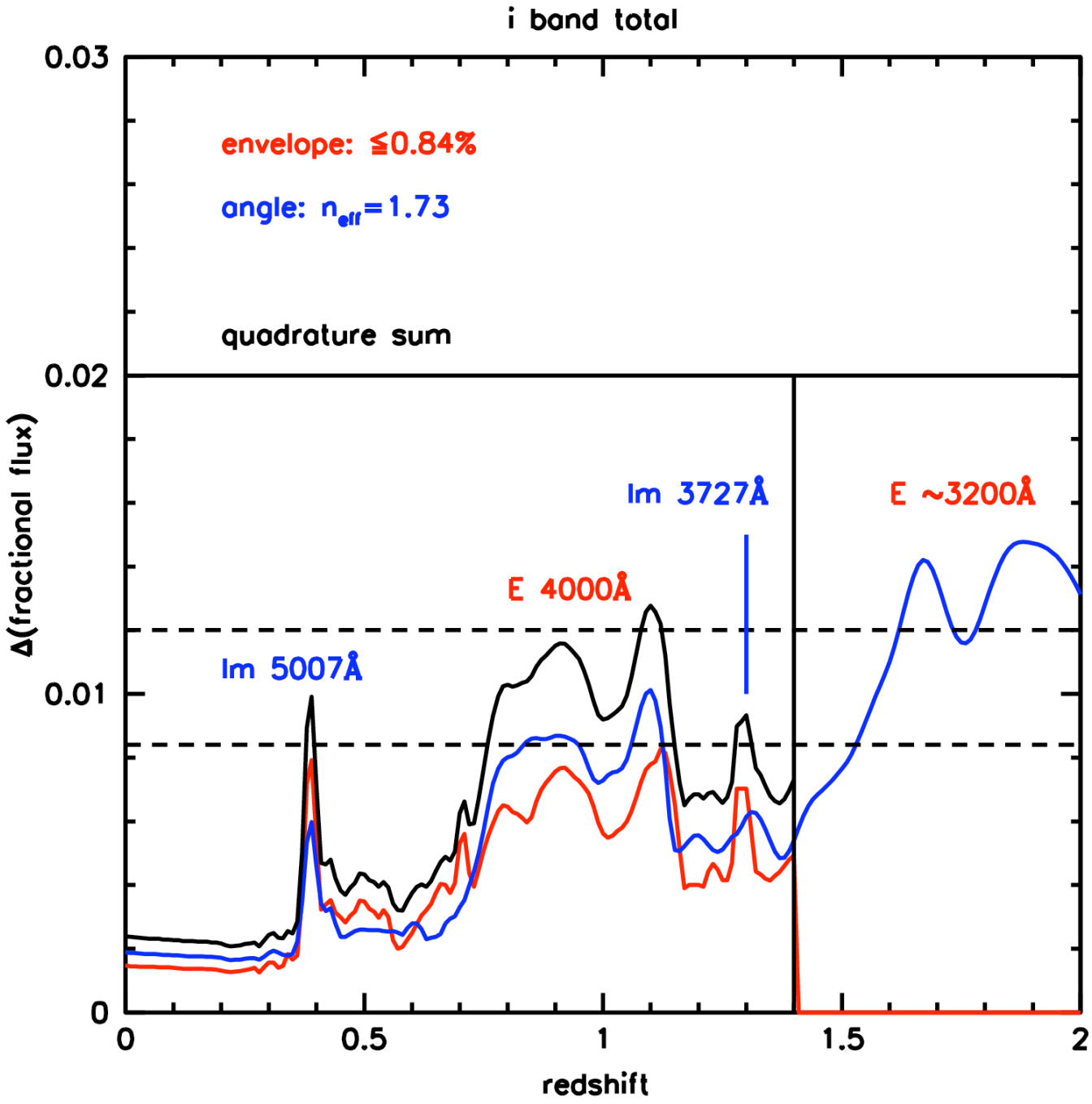
- **Test sets of filter curves fitting within absolute envelopes in order to specify transmission spatial uniformity requirements**

- **Use galaxy SEDs (E, Sbc, Scd, Im) from Bruzual & Charlot GISSEL package: CWW SEDs extended using theoretical models to the UV and IR**
- **Calculate fractional flux differences, vs. *average* of all test filter curves, for 4 galaxy SEDs over redshift ranges relevant to main optical spectral features: 4000Å break, [OII] 3727 and [OIII] 5007 lines**

- **Also account for transmission variations due to changes in incidence angle over focal plane**

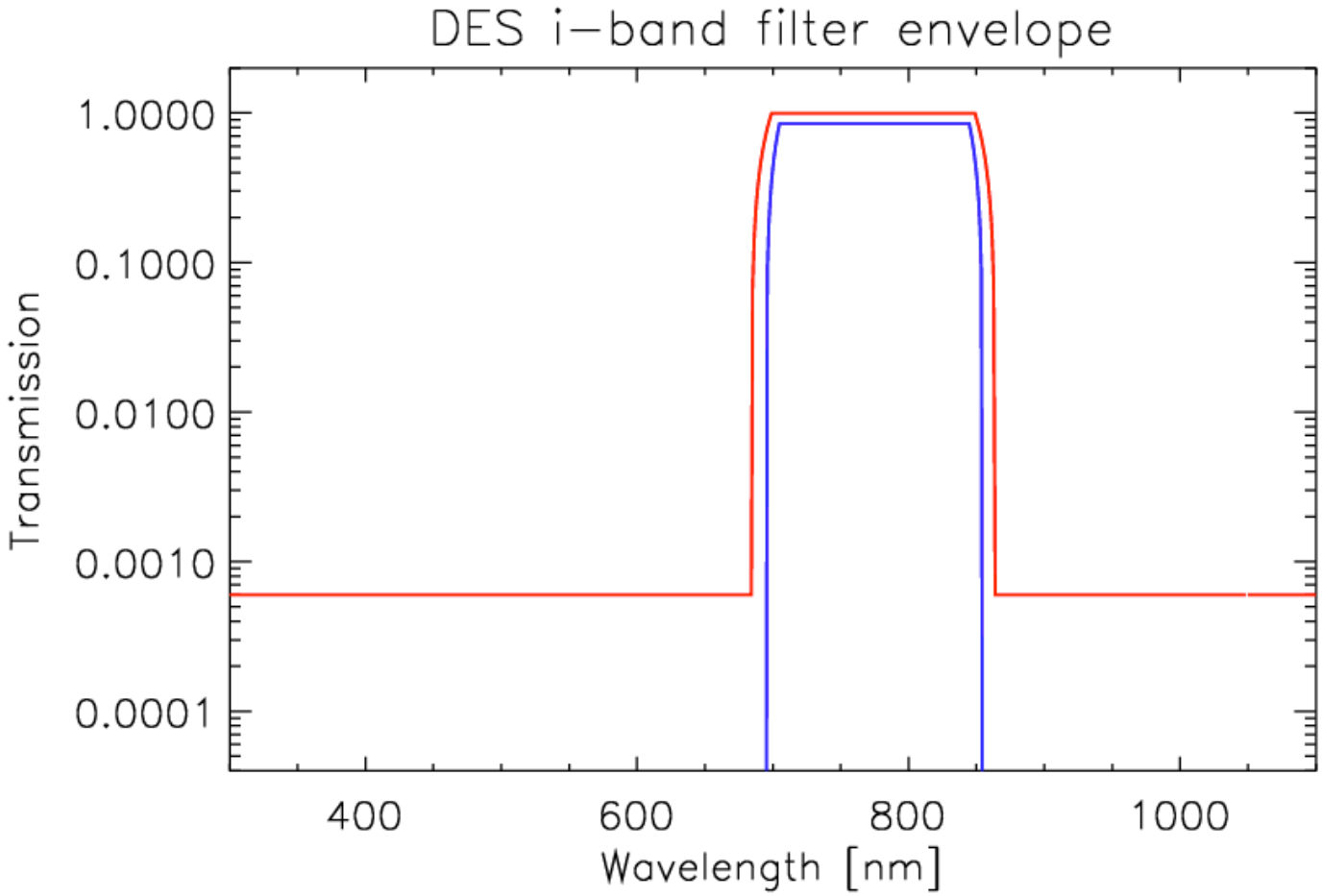
- **Use galaxy analysis results to define "fraction envelopes" on transmission uniformity**

DARK ENERGY
SURVEY


i band total
envelope: ≦0.84%
angle: n_{eff}=1.73
quadrature sum
Im 3727Å
E ~3200Å
E 4000Å
Im 5007Å
Δ(fractional flux)
redshift
0.03
0.02
0.01
0
0
0.5
1
1.5
2

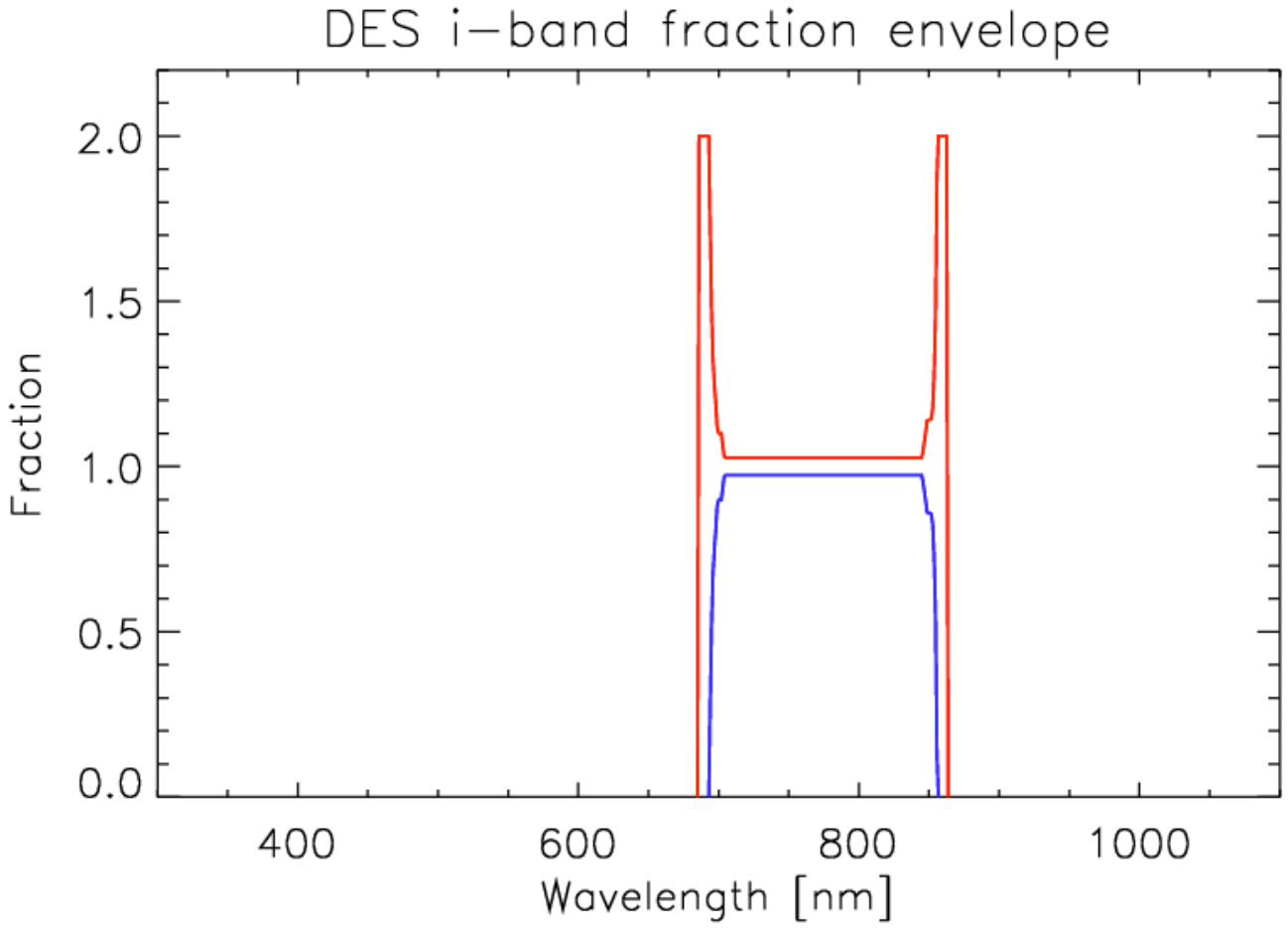
DARK ENERGY SURVEY

Example Absolute Transmission Envelopes for i-band Filter

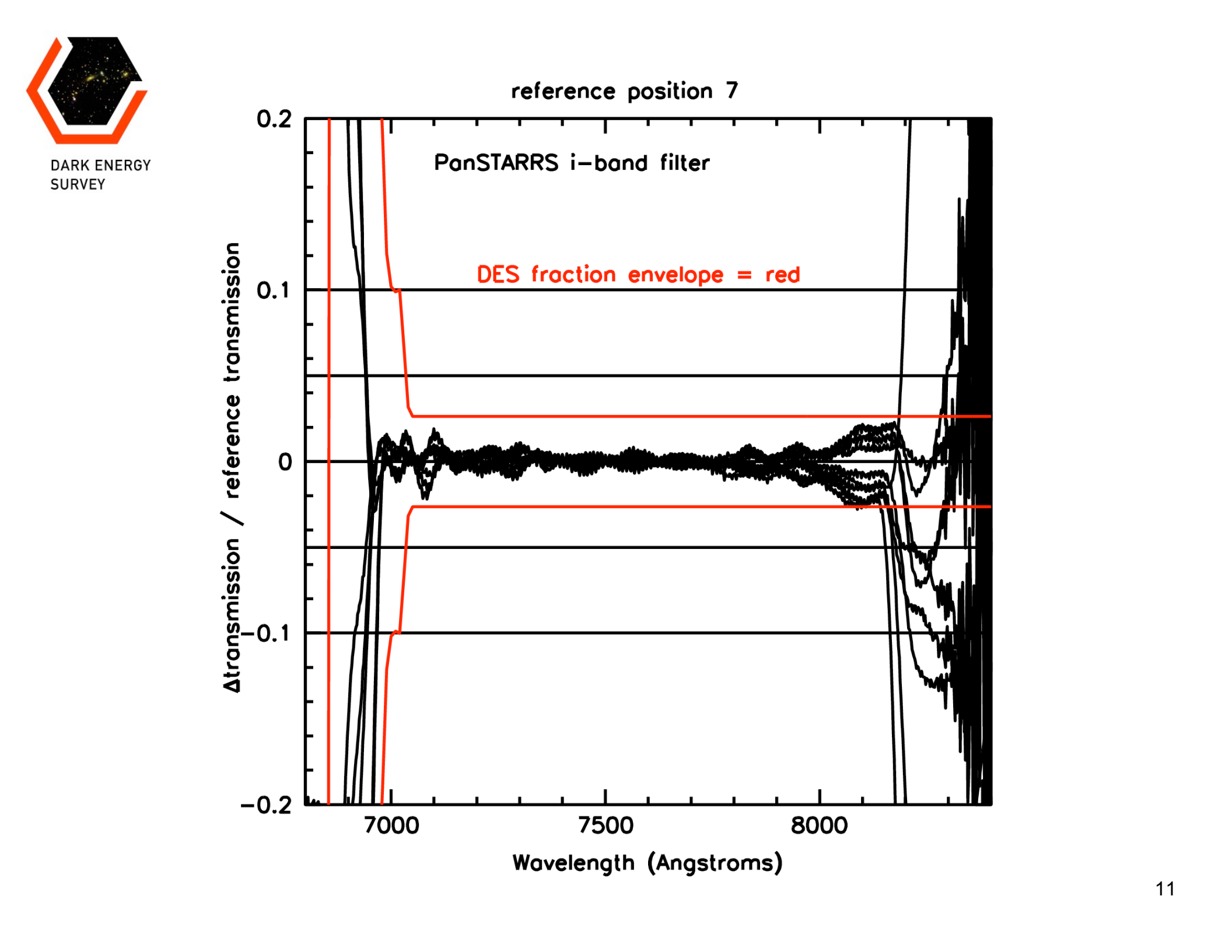


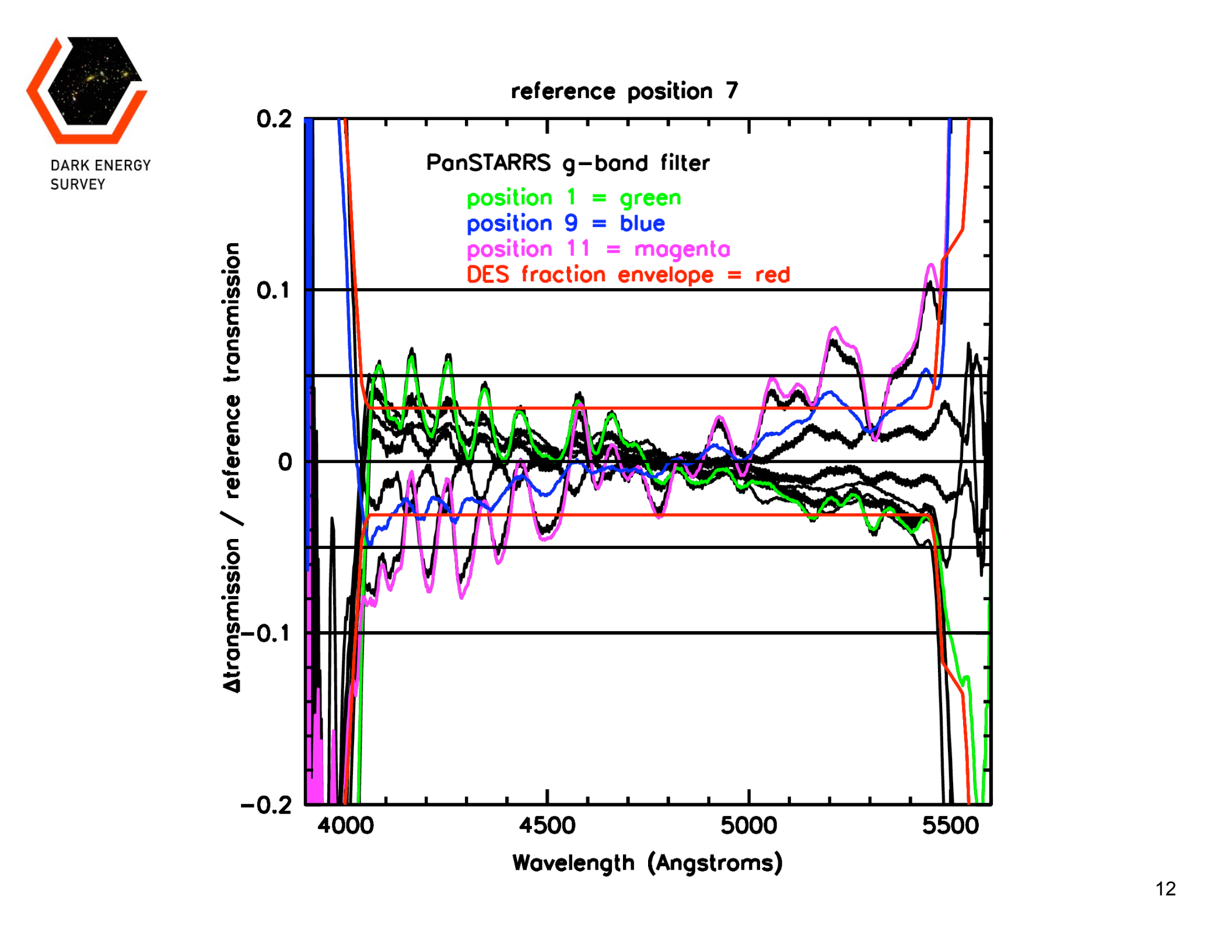
Average filter transmission required to fit within absolute transmission envelopes

Example Transmission Uniformity ("Fraction") Envelopes for i-band Filter



Shape of filter transmission relative to average required to fit within "fraction" envelopes


DARK ENERGY
SURVEY
reference position 7
PanSTARRS i-band filter
DES fraction envelope = red
Δtransmission / reference transmission
0.2
0.1
0
−0.1
−0.2
7000
7500
8000
Wavelength (Angstroms)


DARK ENERGY
SURVEY
reference position 7
PanSTARRS g−band filter
position 1 = green
position 9 = blue
position 11 = magenta
DES fraction envelope = red
Δtransmission / reference transmission
0.2
0.1
0
−0.1
−0.2
4000
4500
5000
5500
Wavelength (Angstroms)

Status

- **Derived filter transmission and spatial uniformity envelopes, based on relative photometric calibration requirements applied to galaxy spectra**

- **Contributions of "envelope" and "incidence angle" effects are about the same, for adopted 0.84% fractional flux cut used to define acceptable envelopes, and for Barr/PanSTARRS n_{eff} values**
- **Current acceptable envelopes should lead to < 1.2% fractional flux difference for galaxies**

- **Vendor responses to filter RFI (see M. Schubnell talk, docdb #1635) indicate it is too expensive and/or difficult to meet our current uniformity specifications, basically about 3% transmission variation over flat parts of filters**

- **Will try using color terms (which are no longer avoidable) and see if non-uniformity of Barr's PanSTARRS filters can still be acceptable for DES**
- **Derive approximate relaxed uniformity specifications**

Revised Filter Transmission Uniformity Analysis, with Color Terms

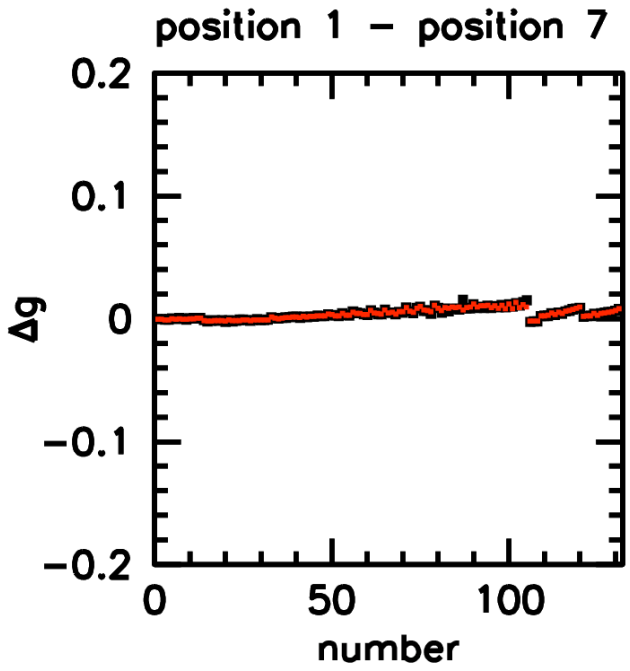
- **Use measured filter transmissions at different radial positions for PanSTARRS filters**
  - **Use position 7 as reference transmission; it's approximately the median (see next slide)**
- **Also use DES filters with gradients applied to derive results more directly applicable to DES, as PanSTARRS filter bandpasses differ in detail**

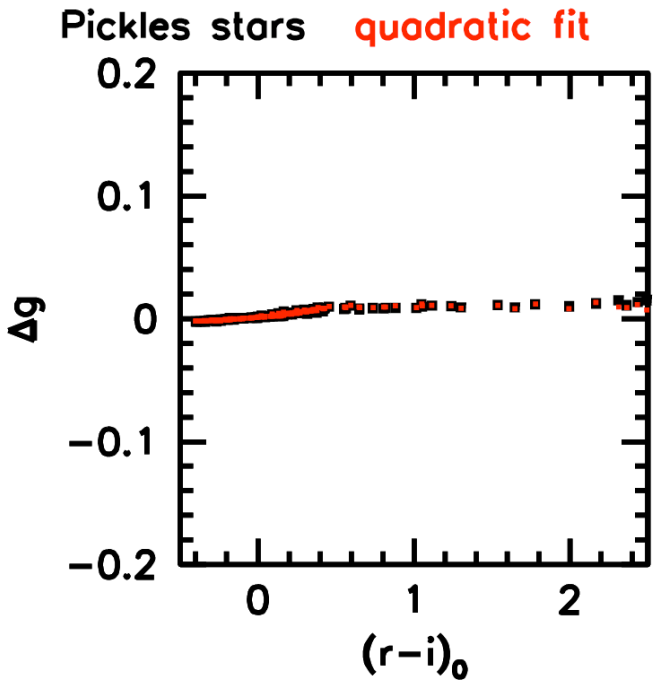
- **Use Pickles stellar library, with 131 spectra of wide range of stellar types, to derive transformations between the magnitudes at different filter positions**
- **Use quadratic fits: e.g., $g - g0 = a + b(g0-r0) + c(g0-r0)^2$**
  - **Use reference colors g-r for g, r-i for r, and i-z for i and z**

- **Use same galaxy SEDs (E, Sbc, Scd, Im) as before**
- **Also consider SN Ia "Hsiao" templates (via John Marriner) at -7, 0, +7, +14 days vs. maximum**

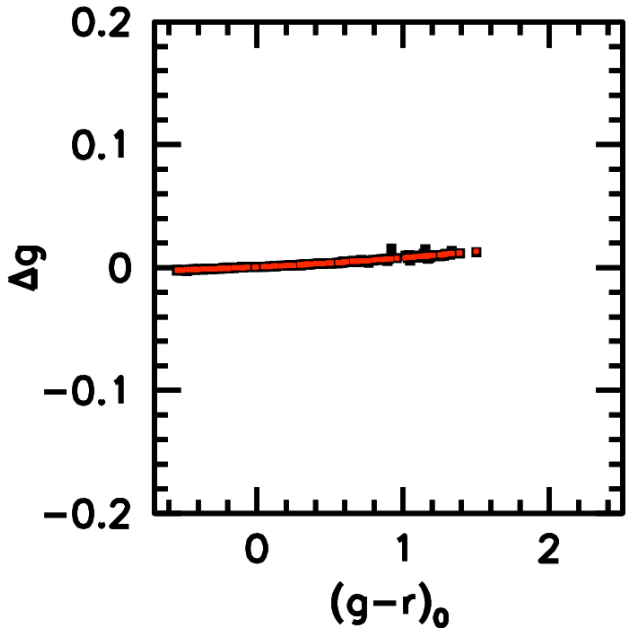
- **Apply color transformations from stars to galaxies and SNe and look at residuals vs. redshift and color**
- **Aim for 1% photometric errors as acceptable for the filter contribution to the total 2% error budget**

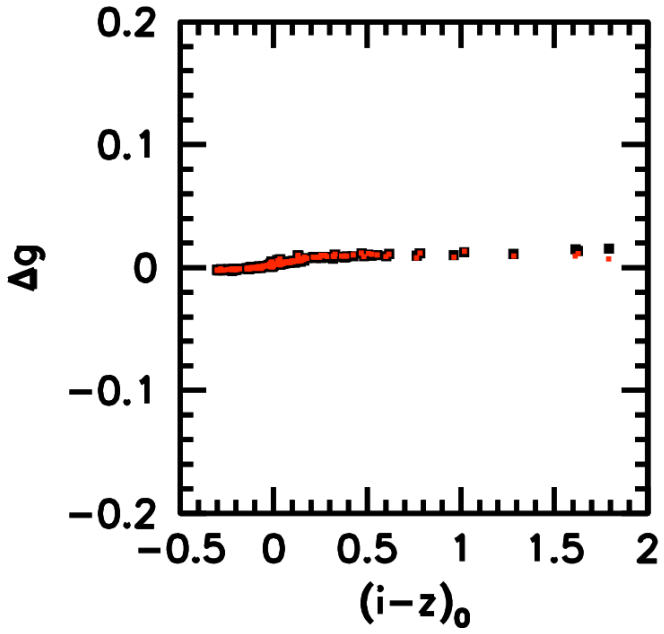
DARK ENERGY
SURVEY

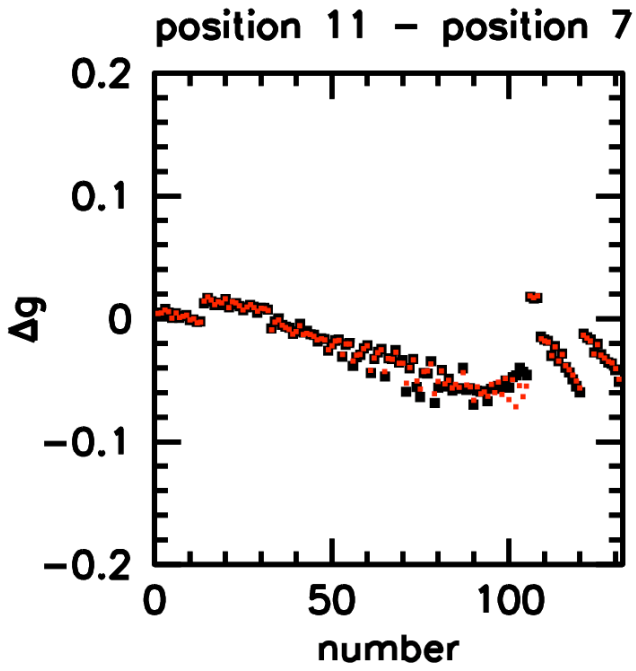


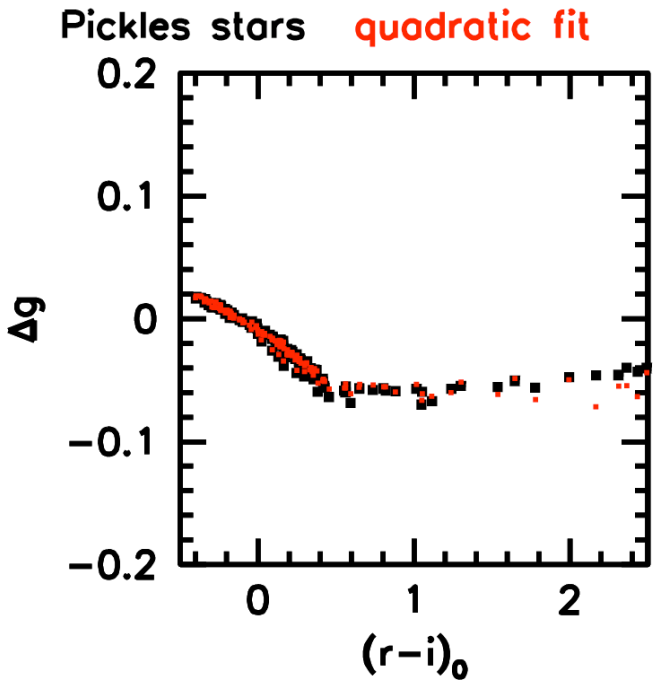


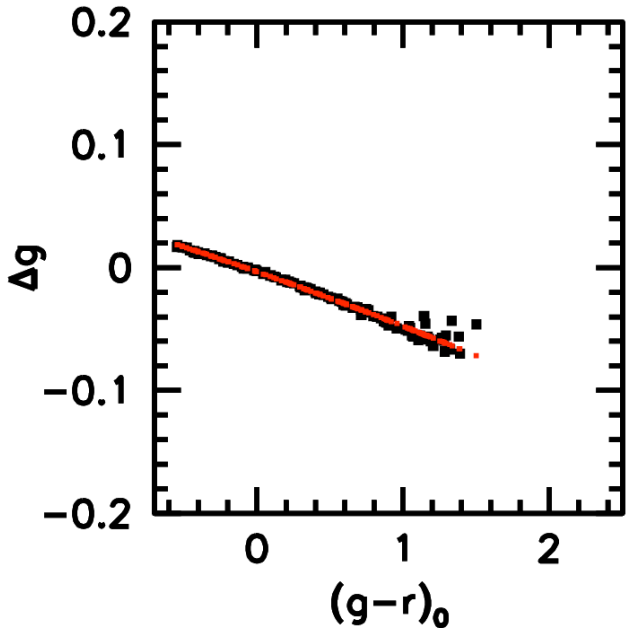
Stars

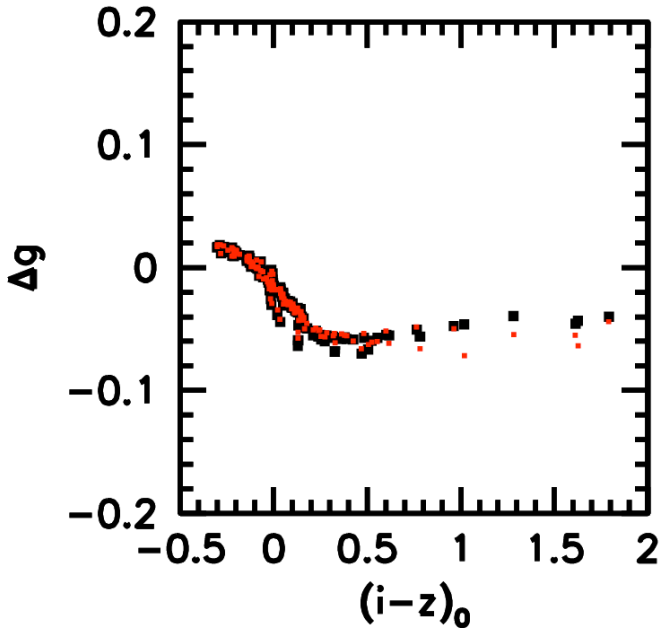




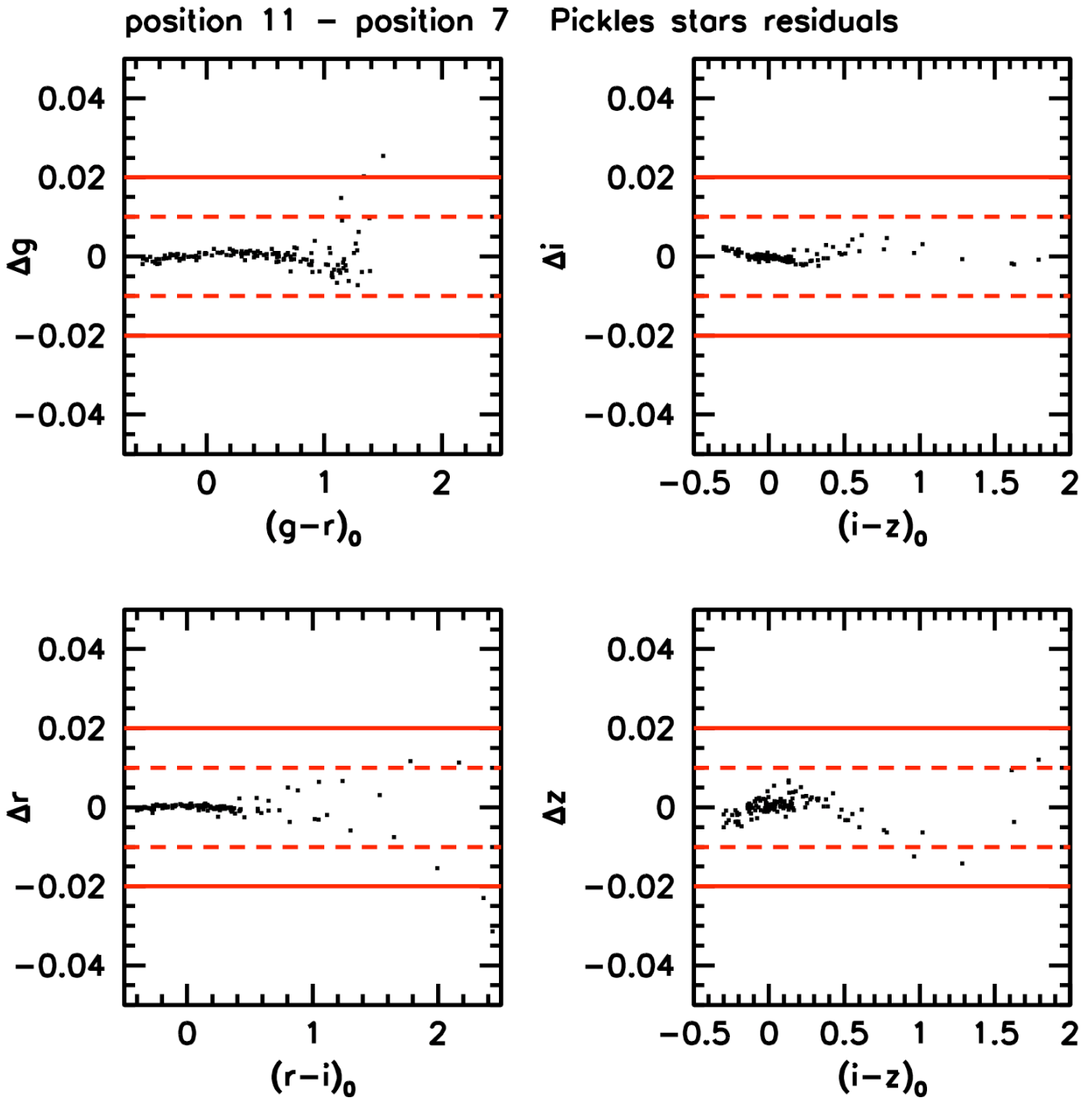

position 11 – position 7
0.2
0.1
0
−0.1
−0.2
Δg
0
50
100
number


Pickles stars
quadratic fit
0.2
0.1
0
−0.1
−0.2
Δg
0
1
2
(r−i)0


0.2
0.1
0
−0.1
−0.2
Δg
0
1
2
(g−r)0

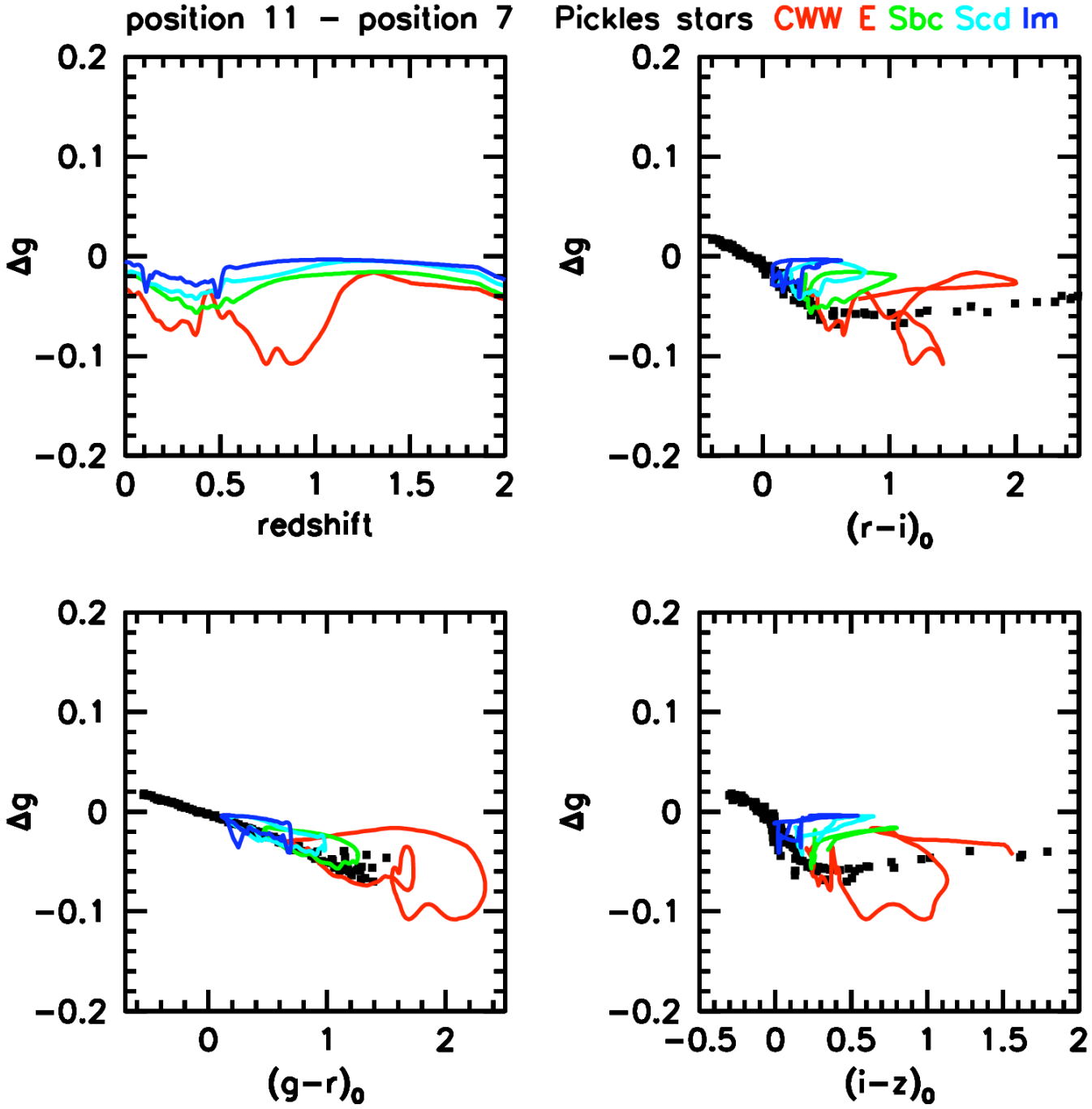

0.2
0.1
0
−0.1
−0.2
Δg
−0.5
0
0.5
1
1.5
2
(i−z)0

Stars



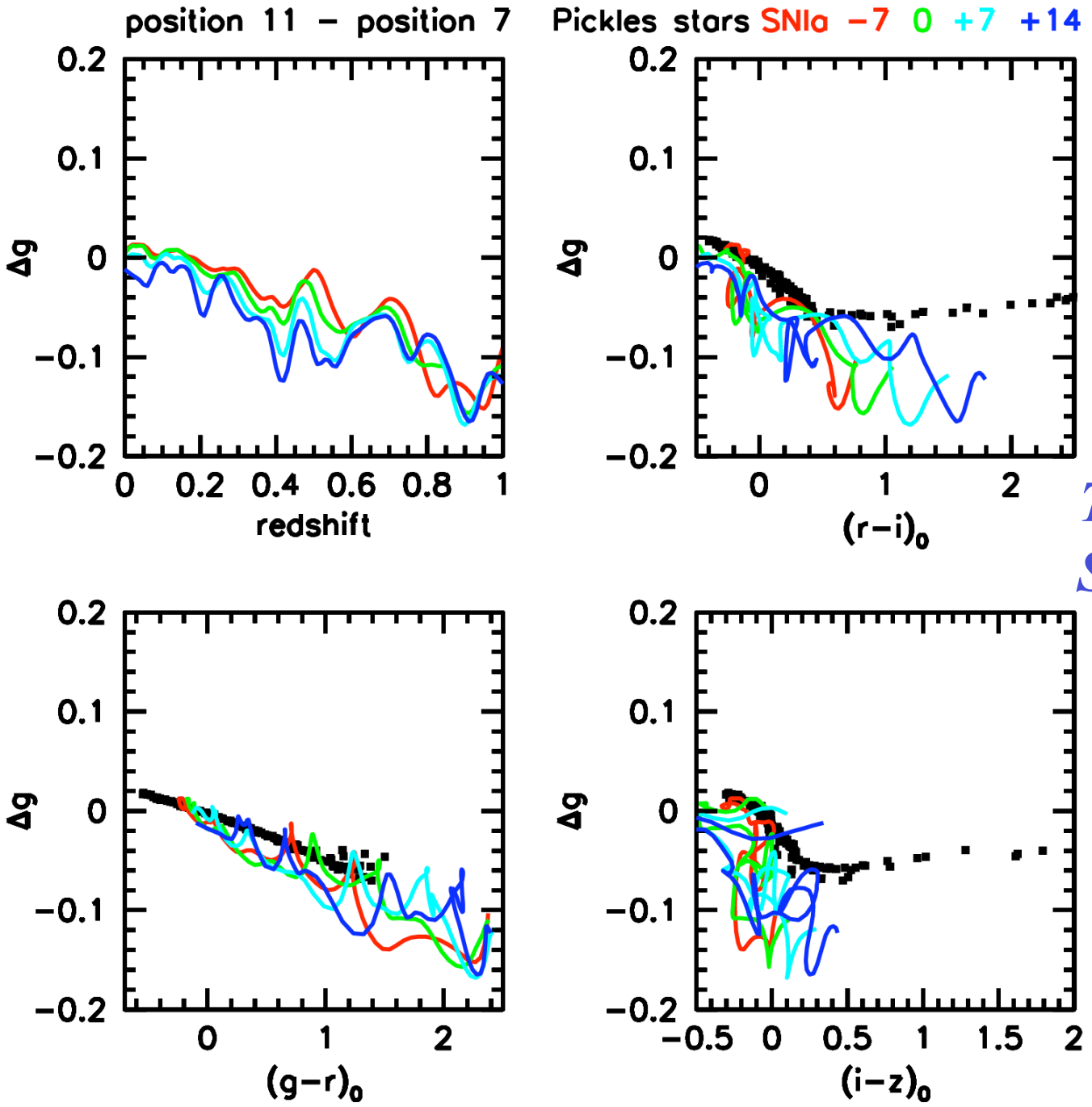
DARK ENERGY SURVEY

Stars

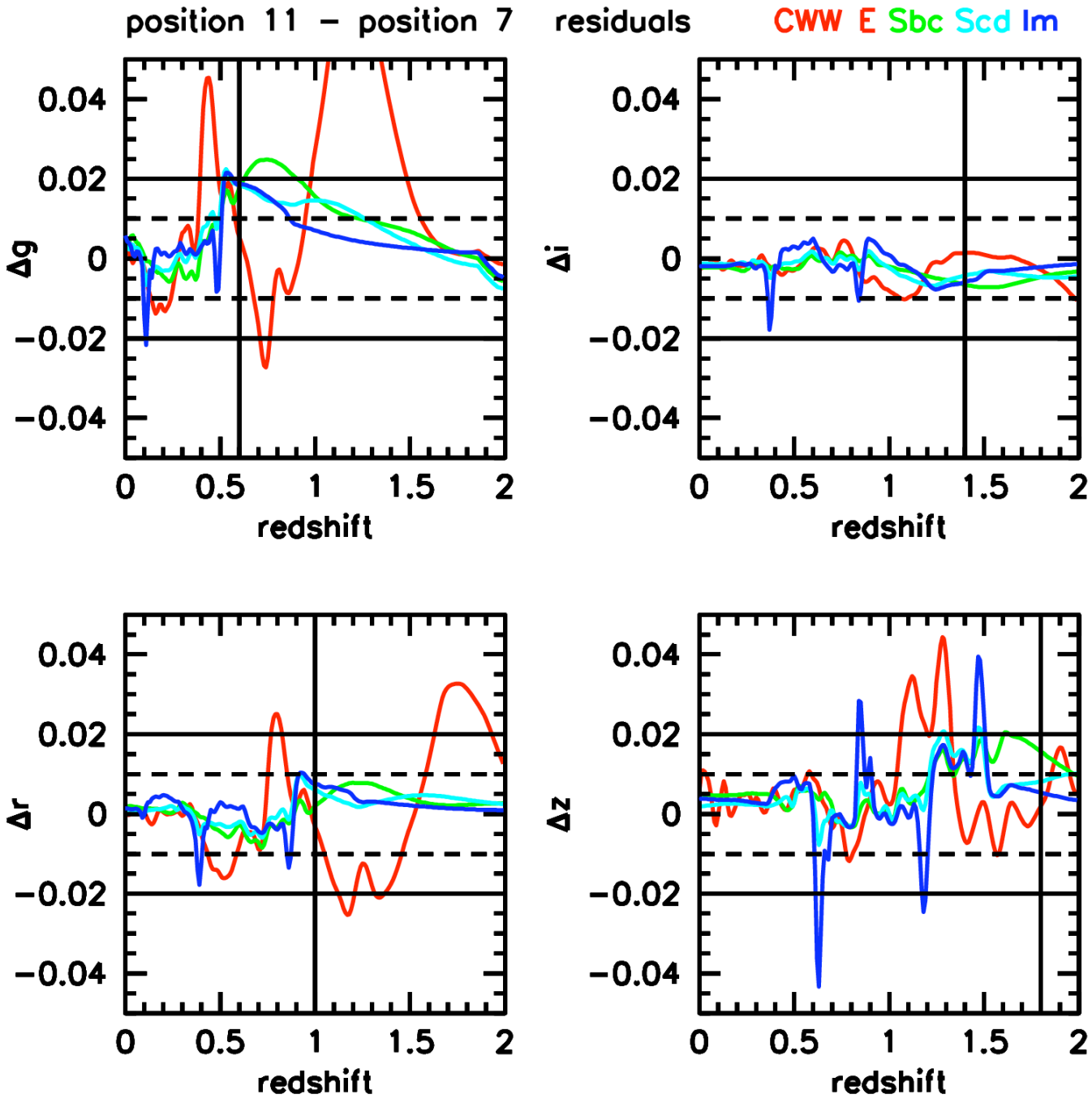

position 11 − position 7
Pickles stars CWW E Sbc Scd Im
Δg
redshift
(r−i)0
(g−r)0
(i−z)0

Galaxies

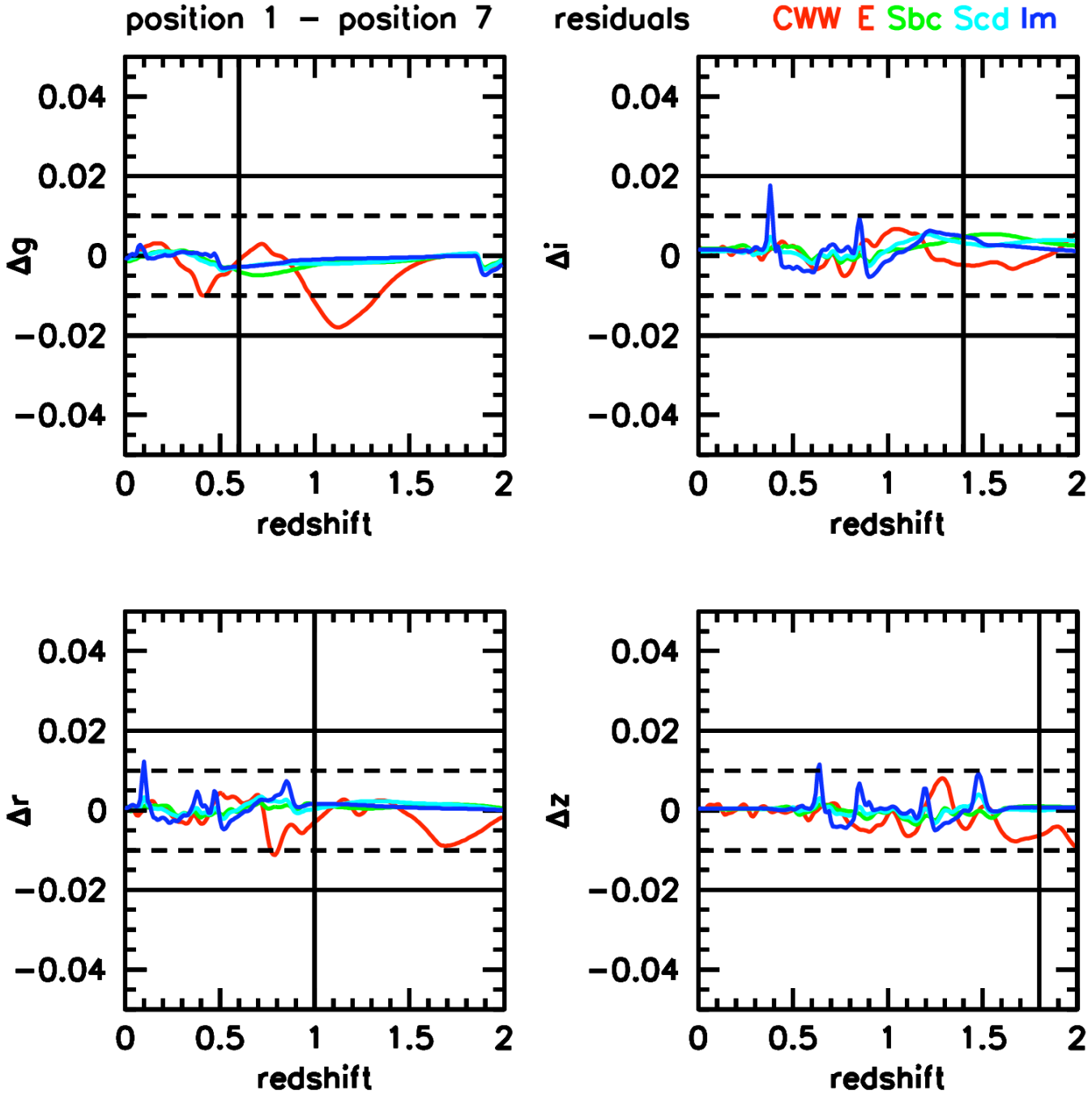
DARK ENERGY
SURVEY



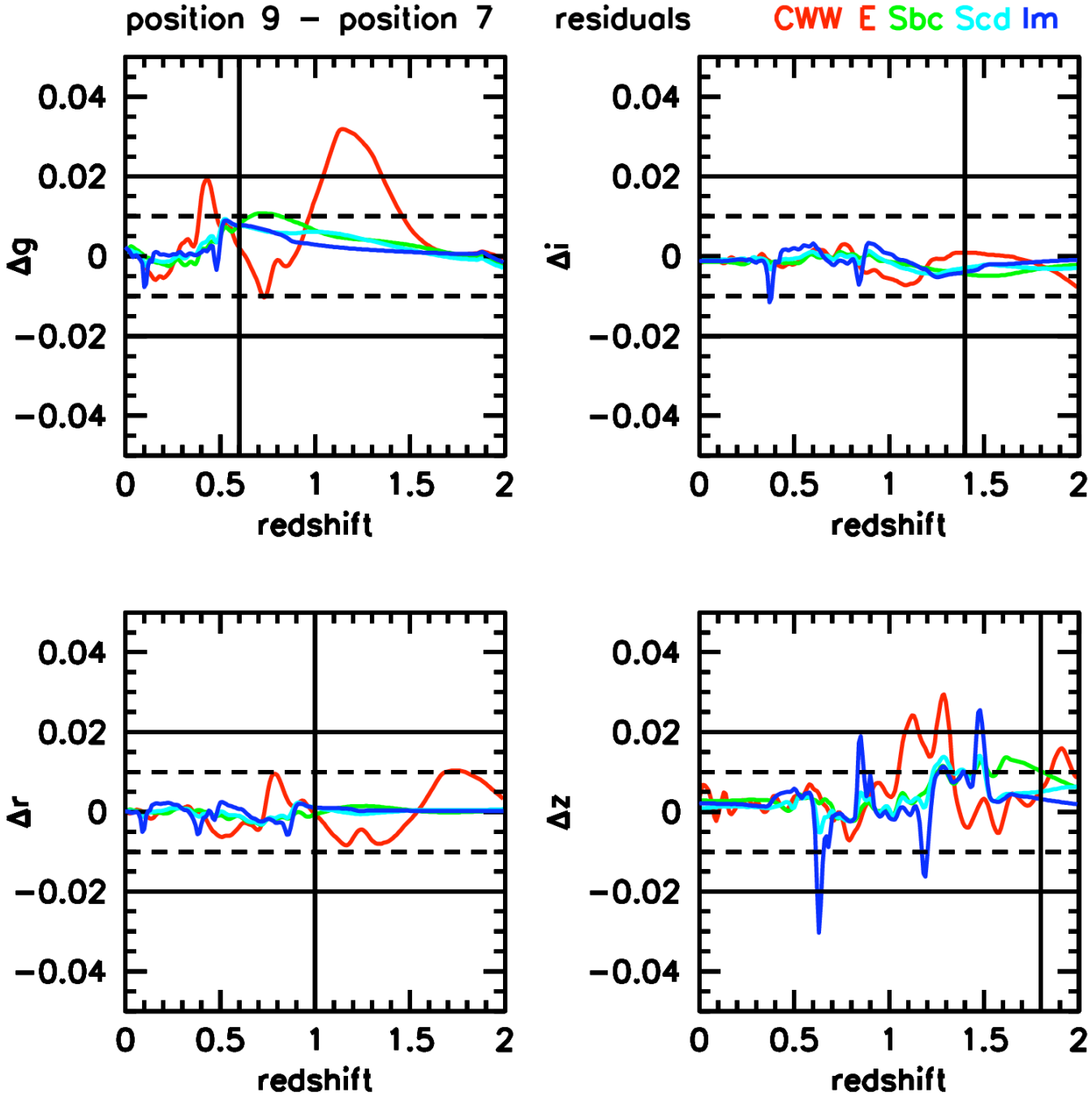
Type Ia Supernovae


position 11 – position 7
residuals
CWW E Sbc Scd Im
Δg
Δi
Δr
Δz
0.04
0.02
0
−0.02
−0.04
0
0.5
1
1.5
2
redshift

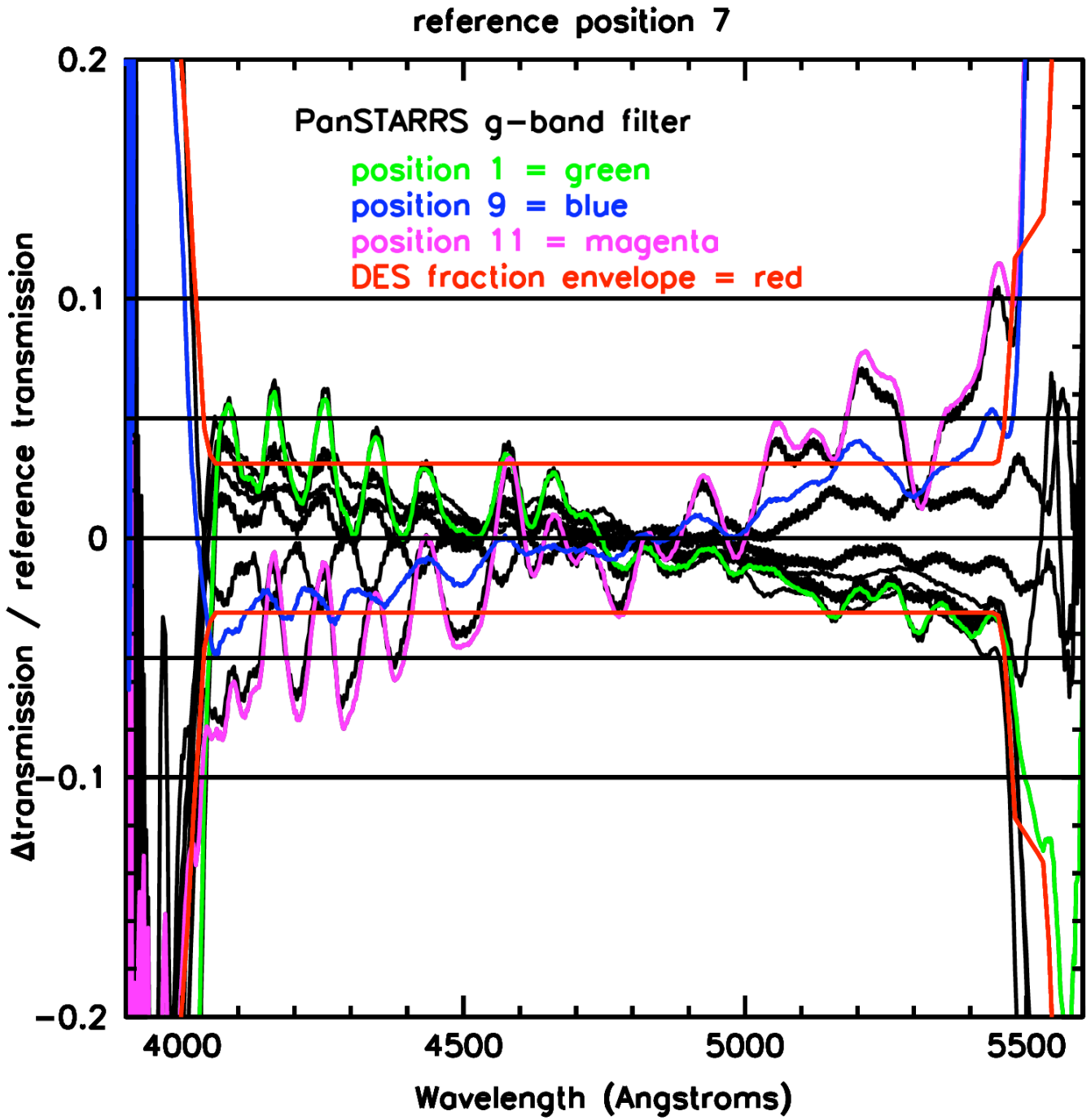
Bad

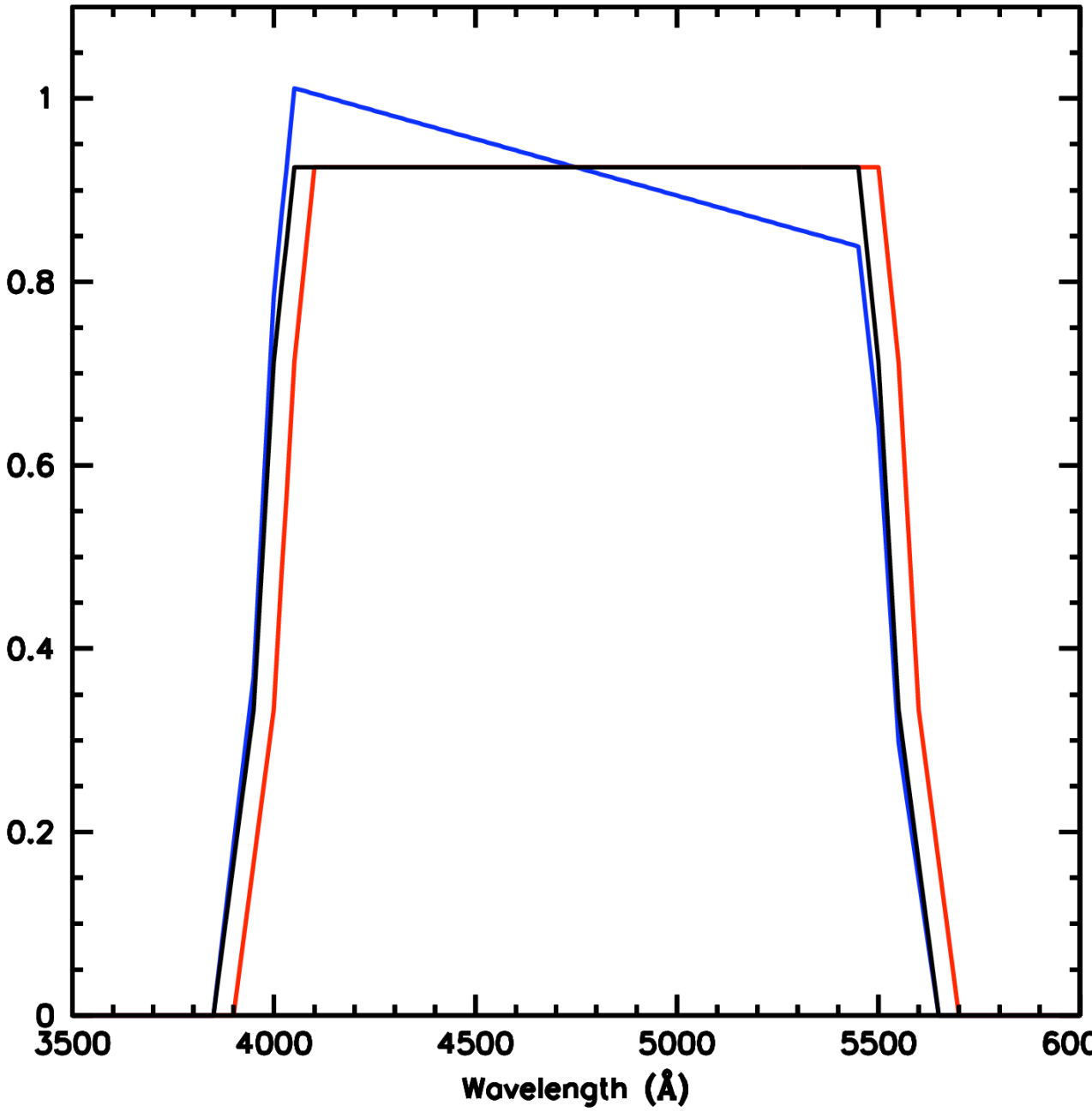

position 1 – position 7
residuals
CWW E Sbc Scd Im
Δg
Δi
Δr
Δz
0.04
0.02
0
−0.02
−0.04
0
0.5
1
1.5
2
redshift

Good


position 9 – position 7
residuals
CWW E Sbc Scd Im
Δg
Δi
Δr
Δz
0.04
0.02
0
−0.02
−0.04
0
0.5
1
1.5
2
redshift

Ok

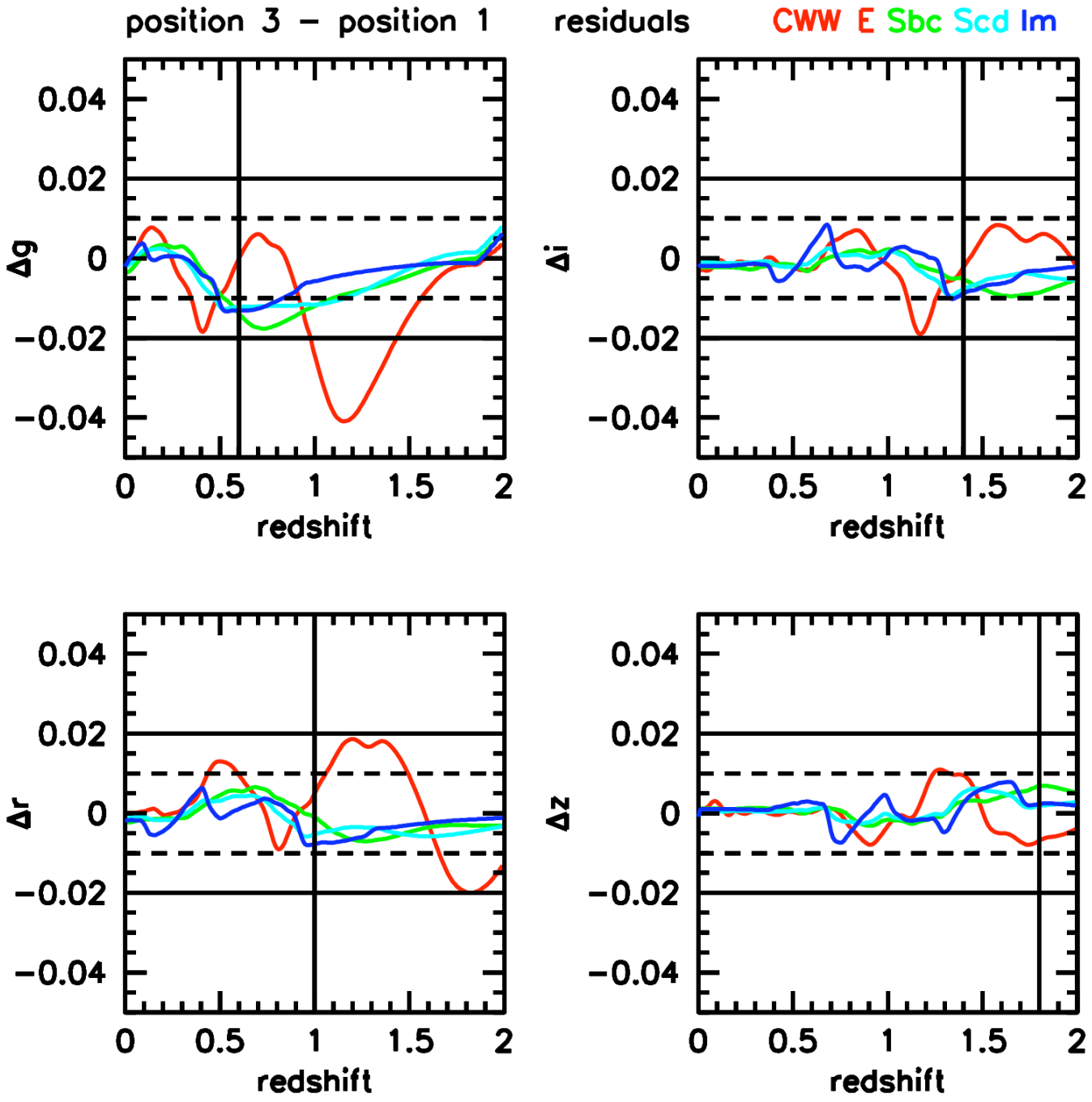

reference position 7
PanSTARRS g−band filter
position 1 = green
position 9 = blue
position 11 = magenta
DES fraction envelope = red
Δtransmission / reference transmission
0.2
0.1
0
−0.1
−0.2
4000
4500
5000
5500
Wavelength (Angstroms)



Original g-band filter in black

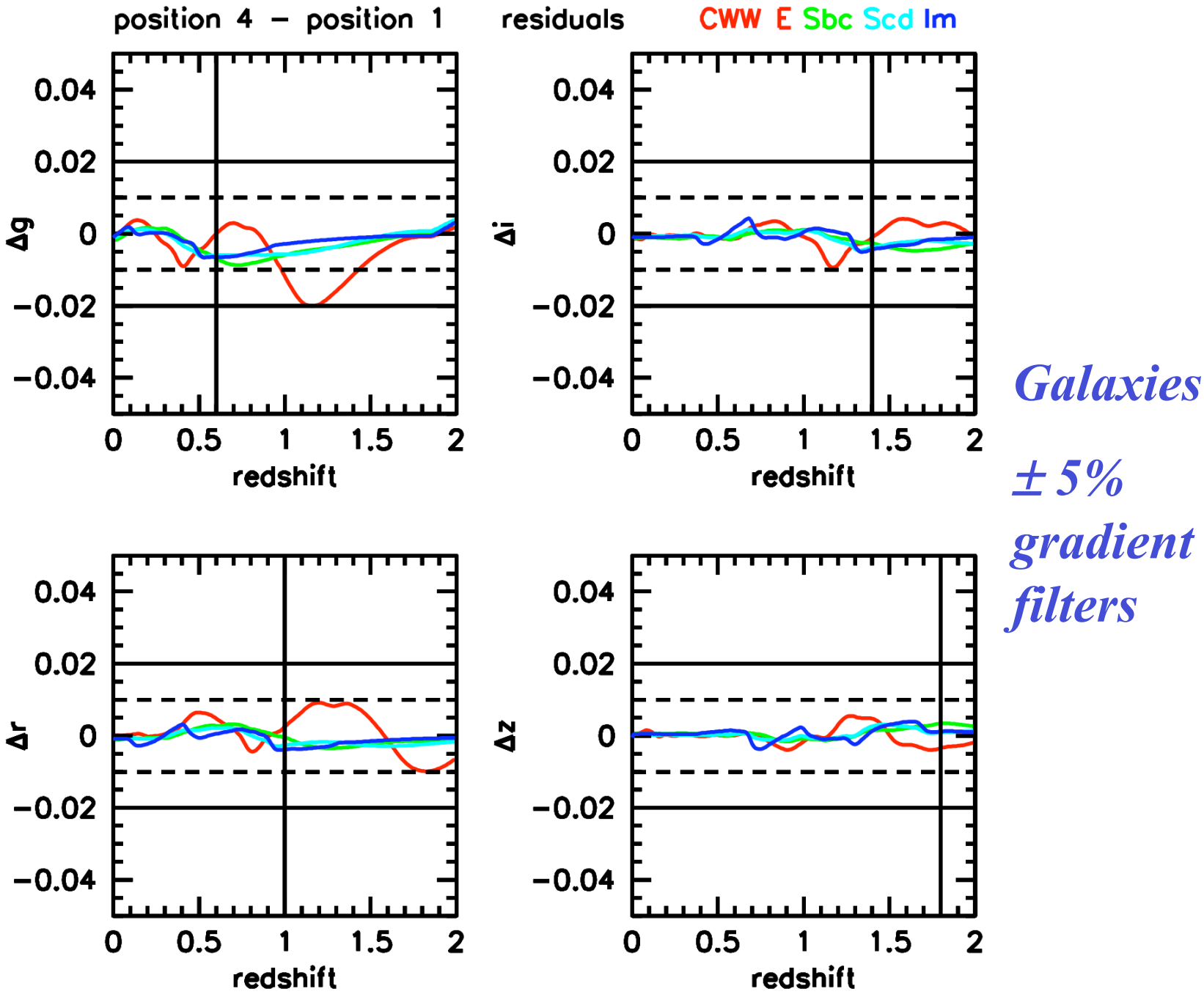
Tilt by gradients of up to ± 10% edge to center

Shift cut-on and cut-off by up to ± 50 Å



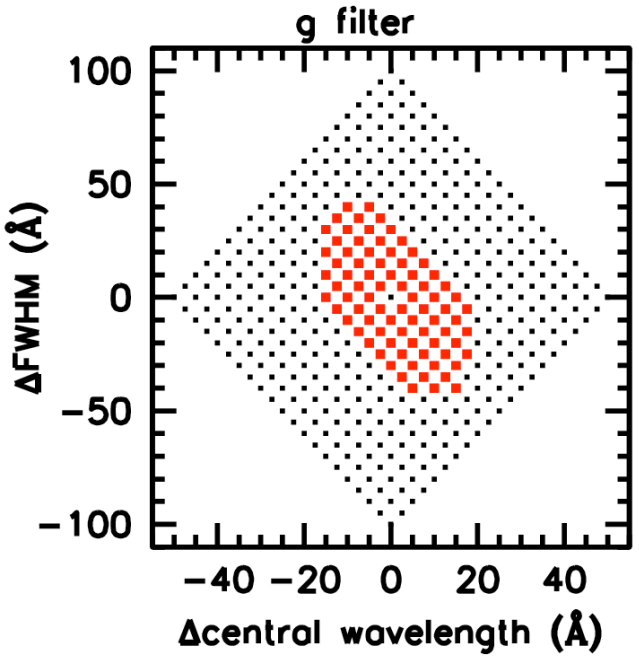
Galaxies

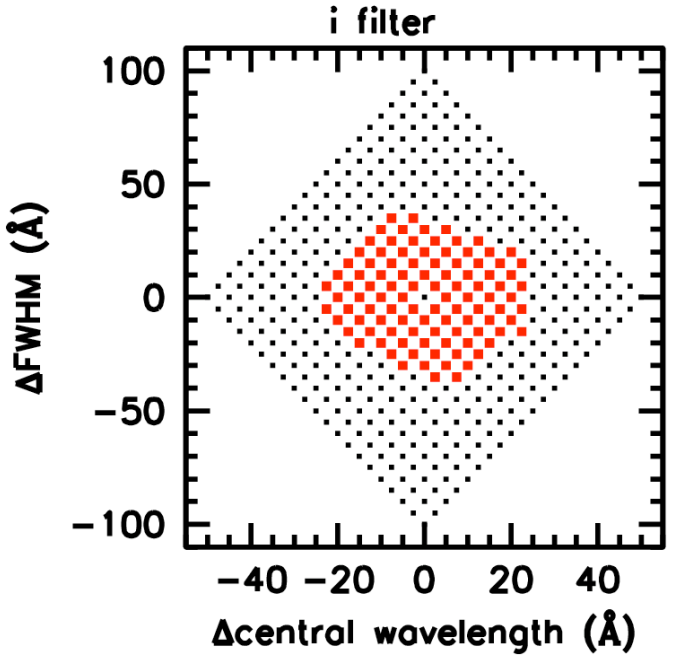
±10% gradient filters

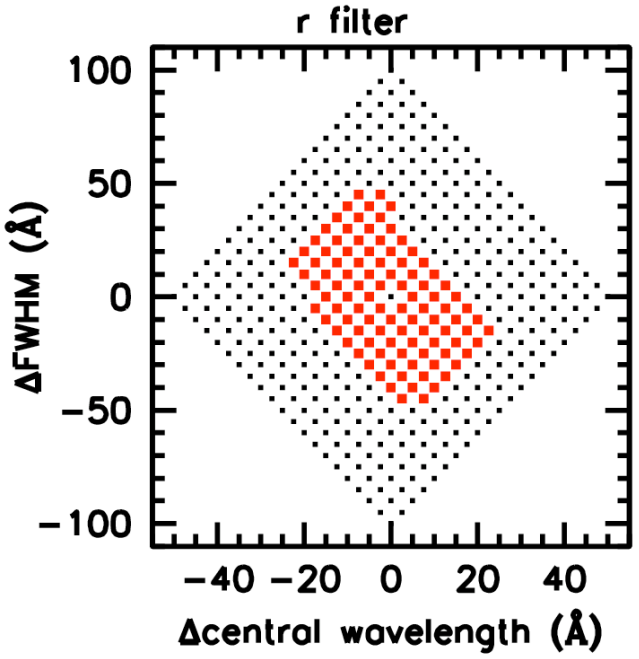


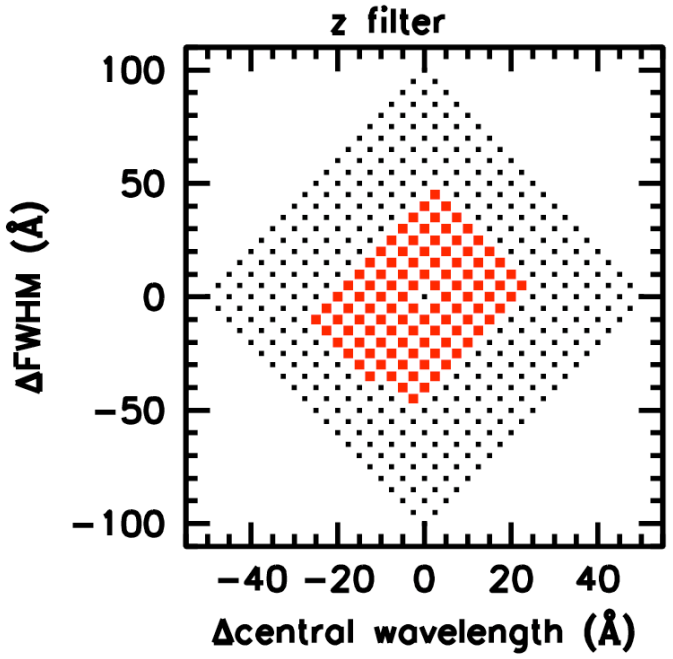
Galaxies

± 5% gradient filters





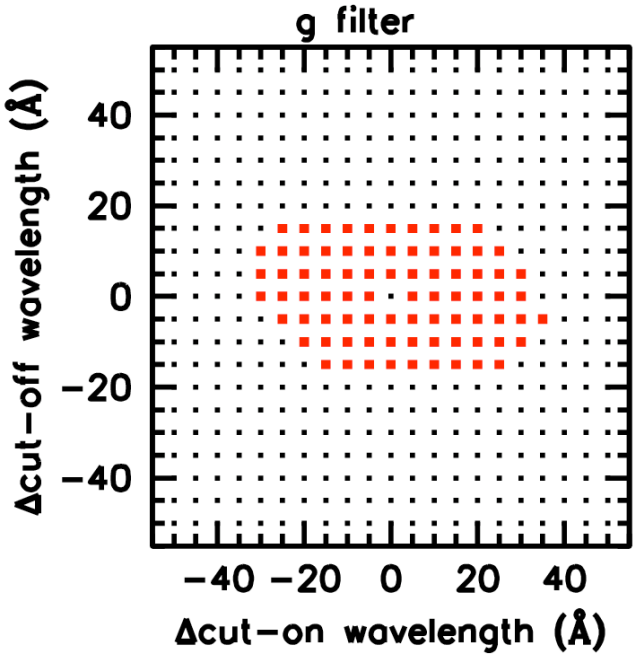


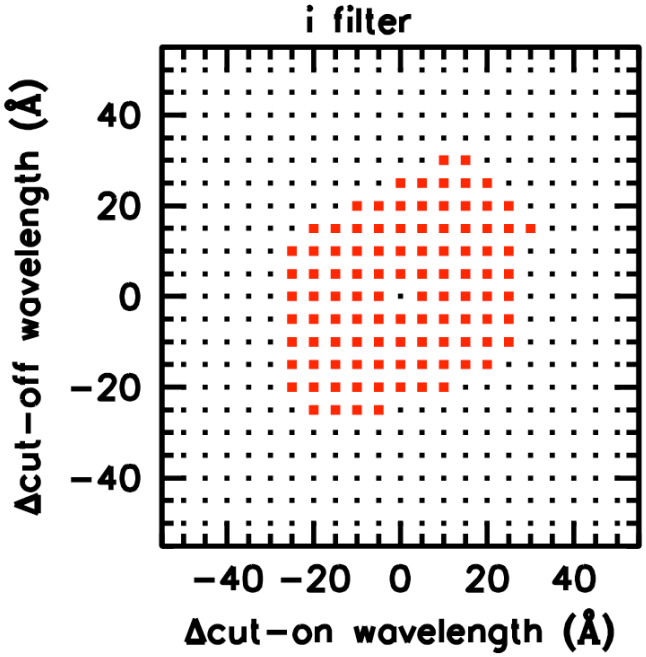


FWHM vs. central wavelengths

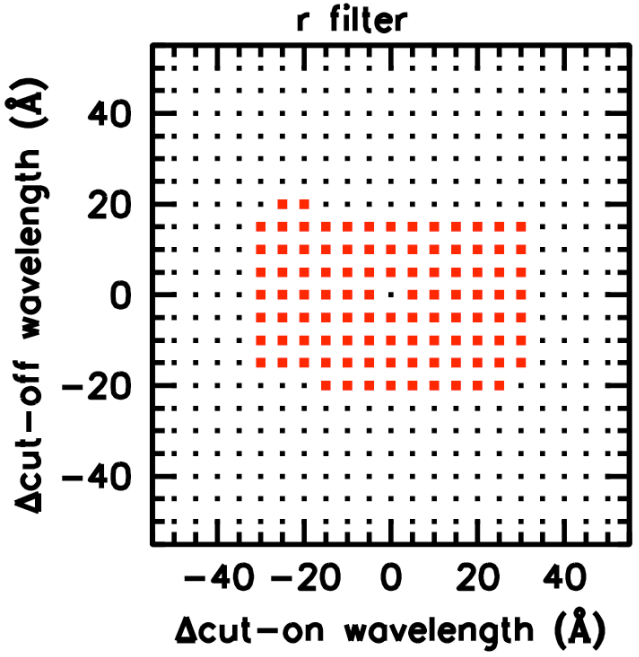
Red points indicate <1% flux errors for galaxies

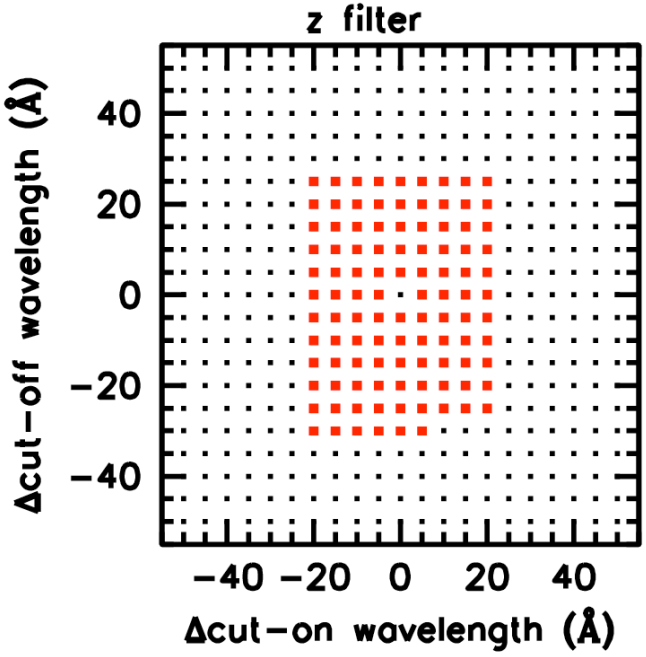
DARK ENERGY
SURVEY





Cut-on vs. cut-off wavelengths (half-maximum points)





Red points indicate <1% flux errors for galaxies

Conclusions

- **Keep same absolute transmission envelopes**
- **Relaxed transmission uniformity specifications possible, by using color terms based on stars, and applying to galaxies and SNe Ia**
- **Gradients (edge to center) < ± 5 – 10% required to keep filter photometric error contribution to < 1%**
  - **About 2-3 times less stringent than original ~3% uniformity specification when color terms not allowed**
  - **PanSTARRS filters from Barr can nearly meet this**
- **Also need typically ± 20 Å requirement on cut-on and cut-off wavelengths (half-maximum points)**

Extra Slides

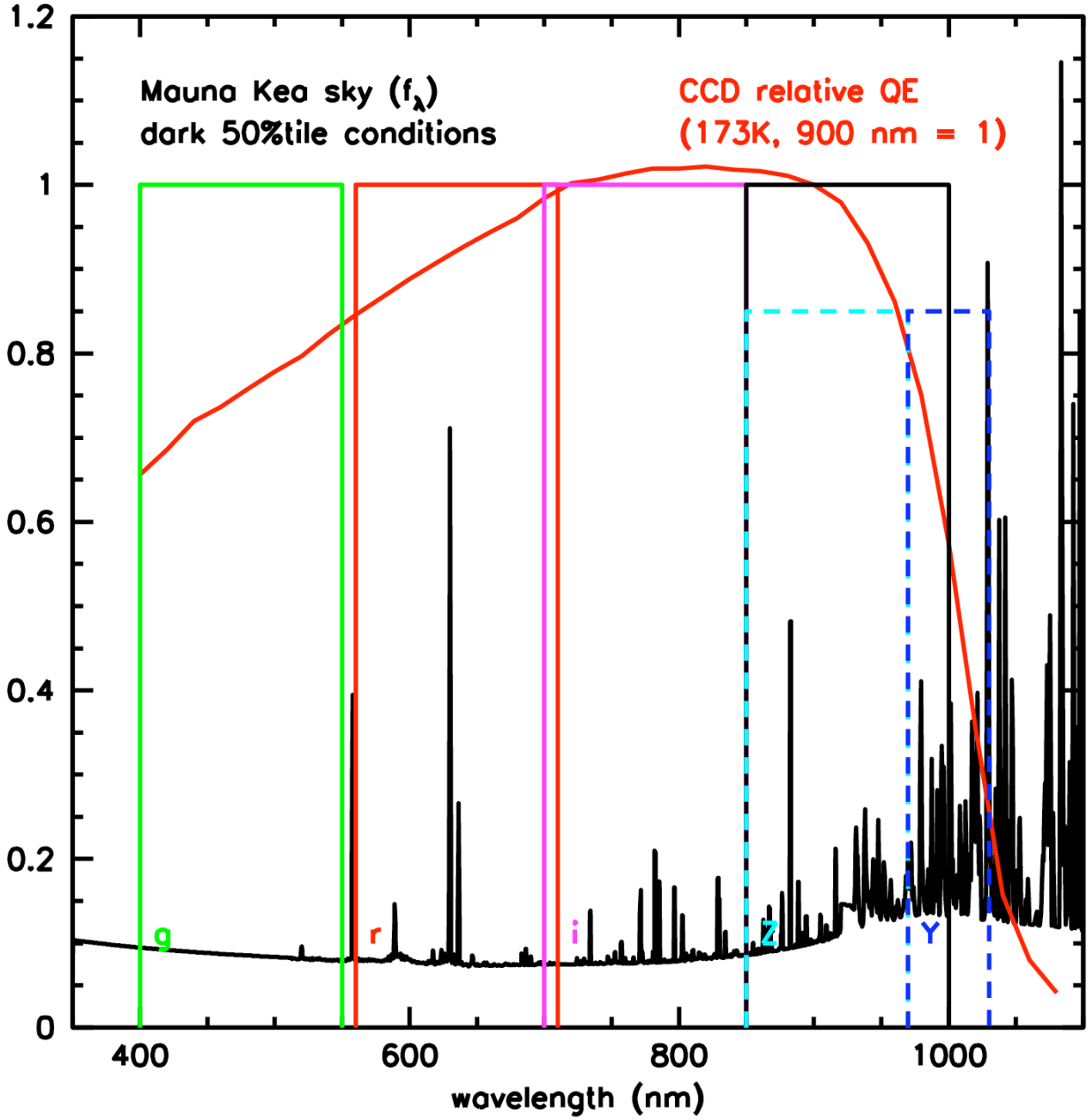
DECam Filter Wavelengths and Transmission Requirements

from DECam Technical Specifications (document #806)

- **TO.15 Filter transmission requirements: > 85% in [*g, r, i, z*]**
- **Table 3 Filter Transmission Requirements**

filter	CWL (nm)	FWHM(nm)	Transmission
g	475	150	85%
r	635	150	85%
i	775	150	85%
z	925	150	85%

DARK ENERGY
SURVEY



DECam Filter Specifications

from DECam Technical Specifications (document #806) and DECam Filter RFI (document #1045)

Substrate dimensions: 620 mm diameter
Substrate material: fused silica
Minimum clear aperture: 610 mm diameter, concentric with substrate diameter
Total thickness: 13 mm
Surface parallelism: 30 arc-seconds or better
Bubble class: 0 (req. 0.1 mm^2 per 100 cm^3; goal 0.03 mm^2 per 100 cm^3)
Maximum bubble size: 0.5 mm diameter
Striae: requirement of 30 nm, goal of 20 nm
Pinhole limits: None with D > 60 microns; no more than one of the size 30-60 microns over an aperture of 50 mm, nor more than a combined equivalent area of 30 microns per 10 mm region of an aperture.
Surface quality: 80-50 scratch-dig
Durability: Mil-C-48479 (moderate abrasion)
Surface quality: Filter edges are to be sealed to prevent moisture incursions into the substrate
Radioisotope limits in filter substrate: U<0.8 ppm, Th<2.5ppm, K<0.03% (by weight)
Radioisotope limits in filter coatings: U<80 ppm, Th<250ppm, K<3% (by weight)

DECam Filter Specifications (cont'd)

from DECam Technical Specifications (document #806) and DECam Filter RFI (document #1045)

Operating focal ratio: f/2.9
Optical thickness: All filters shall have the same optical thickness, ±0.10 mm air equivalent.
Transmitted wave error in 125 mm diameter sub-aperture: < λ/4
Beam Angles of Incidence: 0 – 4 degrees for f/2.9 beams (maximum range 0-12 deg)
Coatings: All air-glass interfaces are to be anti-reflection (AR) coated.
Predicted performance of the AR coatings should be provided with the quotation.
Filter substrate edges to be sealed against moisture penetration.
Transmission: Specified by absolute transmission envelopes vs. wavelength,
and spatial uniformity specified by "fraction envelopes" (see later this talk)

Normal operating temperature: -5C to 27C
Survival temperature range: -56C to 40C
Normal operating humidity range: 0-60% (dry nitrogen environment)
Survival humidity range: 0-100%
Normal operating elevation: 2200 m (7220 ft)
Normal operating pressure: 570-590 Torr
Operational lifetime: 10 years

Top Level Photometric Calibration Science Requirements (version 6.5 draft of document)

- **S-16 The magnitudes of an object may be calculated to within 2% by convolving the spectrum of the object with the system response curves. This requirement assumes that the spectra are spectrophotometrically calibrated and that the system response curves are absolute.**
  - ***This is the total photometric calibration requirement***

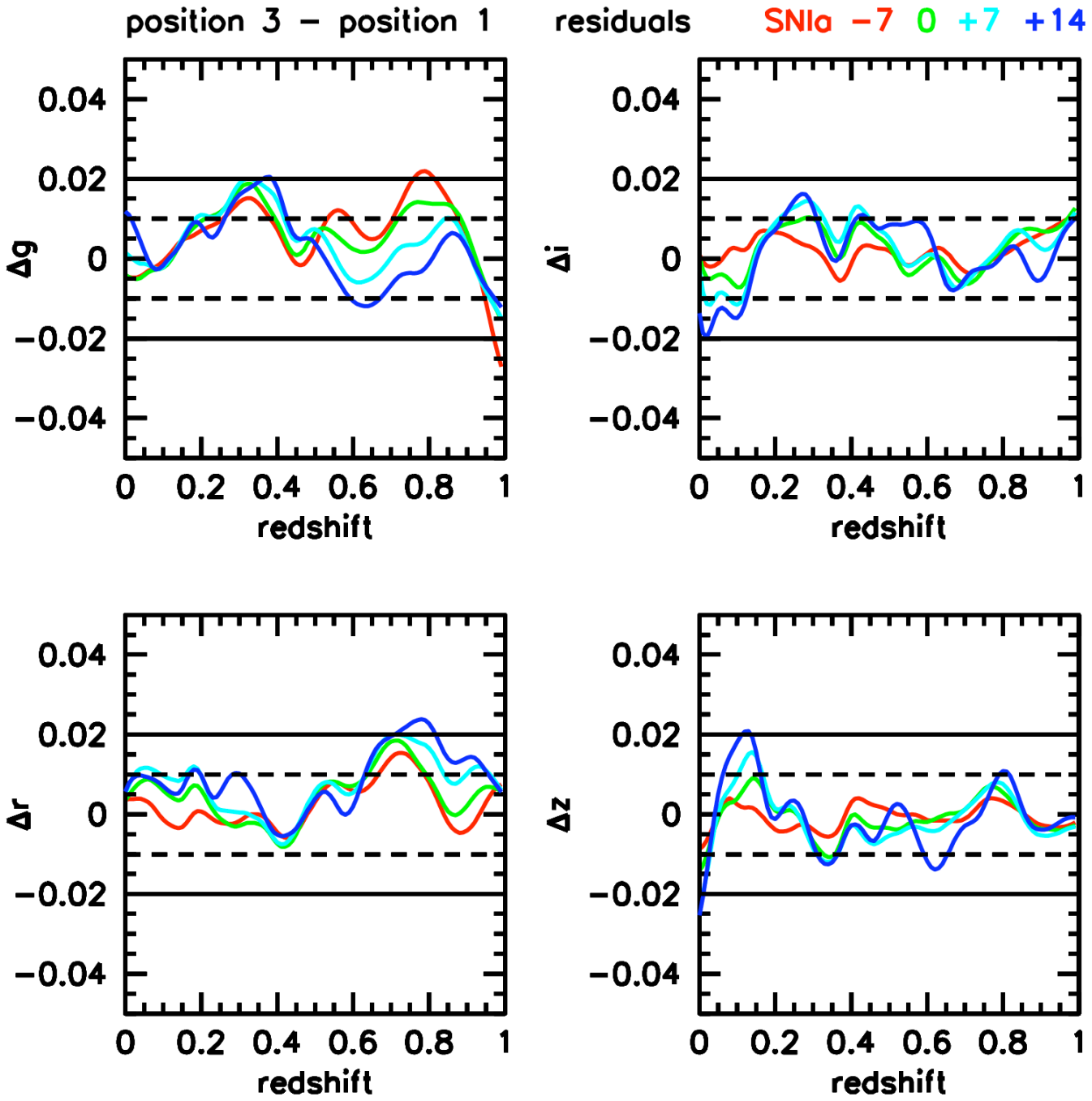
- **S-17 The magnitudes vary only by $-2.5 \log f_2/f_1$, independent of position in the final map to within 2% (1% enhanced goal), where f_2/f_1 is the ratio of photon fluxes. This is to be true in *g, r, i, z* individually.**
  - ***This is basically the relative photometric calibration requirement***
  - ***We'll focus on this***

- **S-18 The magnitudes have an absolute zero point that is well-defined and known to 0.5%. The magnitudes will be on the natural instrument system.**
  - ***This is basically the absolute photometric calibration requirement***

Proposed Relative Photometric Calibration Science Requirements

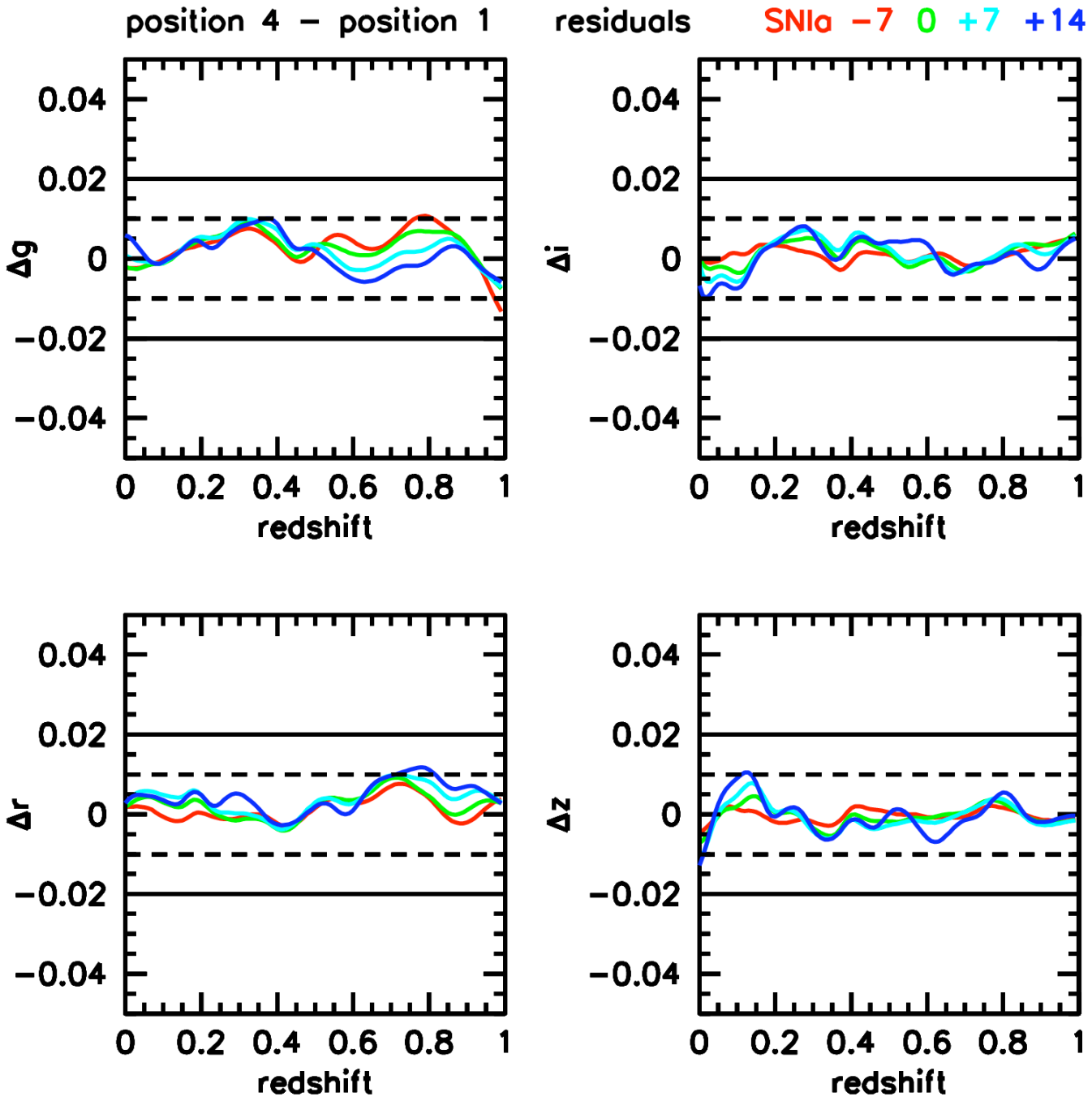
- **S-19** **Uncorrected nonlinearities** due to imperfect shutter timing and nonlinear CCD/amplifier gain shall be less than 0.3%, measured as the peak error between shortest and longest exposure times, and between the faintest and brightest unsaturated stars.
- **S-20** The **aperture correction** shall have an internal rms error no bigger than 0.6% for any CCD and seeing between 0.8" and 1.5".
- **S-21** The rms photometric errors due to **imperfect flatfielding** (including errors in removing the ghost image of the night sky and removing other stray light sources) will be no worse than 0.84%.
- **S-22** The rms photometric variations due to spatial changes in the **shape of the system optical transmission** (telescope, corrector lenses and coatings, and filters) will be no worse than 0.84%.
- **S-23** The rms photometric variations due to spatial changes in the **shape of the CCD QE vs. wavelength** curve will be no worse than 0.84%.
- **S-24** The rms photometric errors due to imperfect removal, using the global relative photometric calibration solution, of temporal and spatial changes in the **atmospheric transparency and extinction**, will be no worse than 0.84%.
- **S-25** The rms photometric errors due to imperfect corrections for **astrometric and other distortions** on the focal plane (including those due to the optical design and to the CCD "glowing edges") will be no worse than 0.84%.

- **Kept 1st two requirements at 0.3% and 0.6%**
- **Leaves remaining 1.88% for last 5 terms, divide by sqrt(5) to get 0.84% per requirement**



SNe Ia

±10% gradient filters



SNe Ia

± 5% gradient filters

z/Z, Y Filter Issues

- **Need to assess impact of including/excluding variable atmospheric absorption feature at 9300-9600 Å to finalize z/Z bandpass**
  - **Excluding it improves photometric calibration**
  - **Including it improves S/N, e.g., for redshift = 1 elliptical galaxy**
    - **Z (8500-9700 Å) gives 30% better S/N cf. Z (8500-9200 Å)**
    - **z (8500-10000 Å) gives 50% better S/N cf. Z(8500-9200 Å)**
  - **Excluding it improves photometric calibration**
    - **Both LSST and PanSTARRS are using such a Z filter**
    - **Need data on absorption variability to quantify impact on calibration errors**

- **Y filter bandpass**
  - **Consistent with VISTA, LSST, and PanSTARRS choices of blue cutoff**
  - **Need to check DES CCD QE turn-off variability to finalize red cutoff**
  - **Need to define Y-band science requirements to confirm if larger calibration uncertainties (> 2 %) are acceptable**